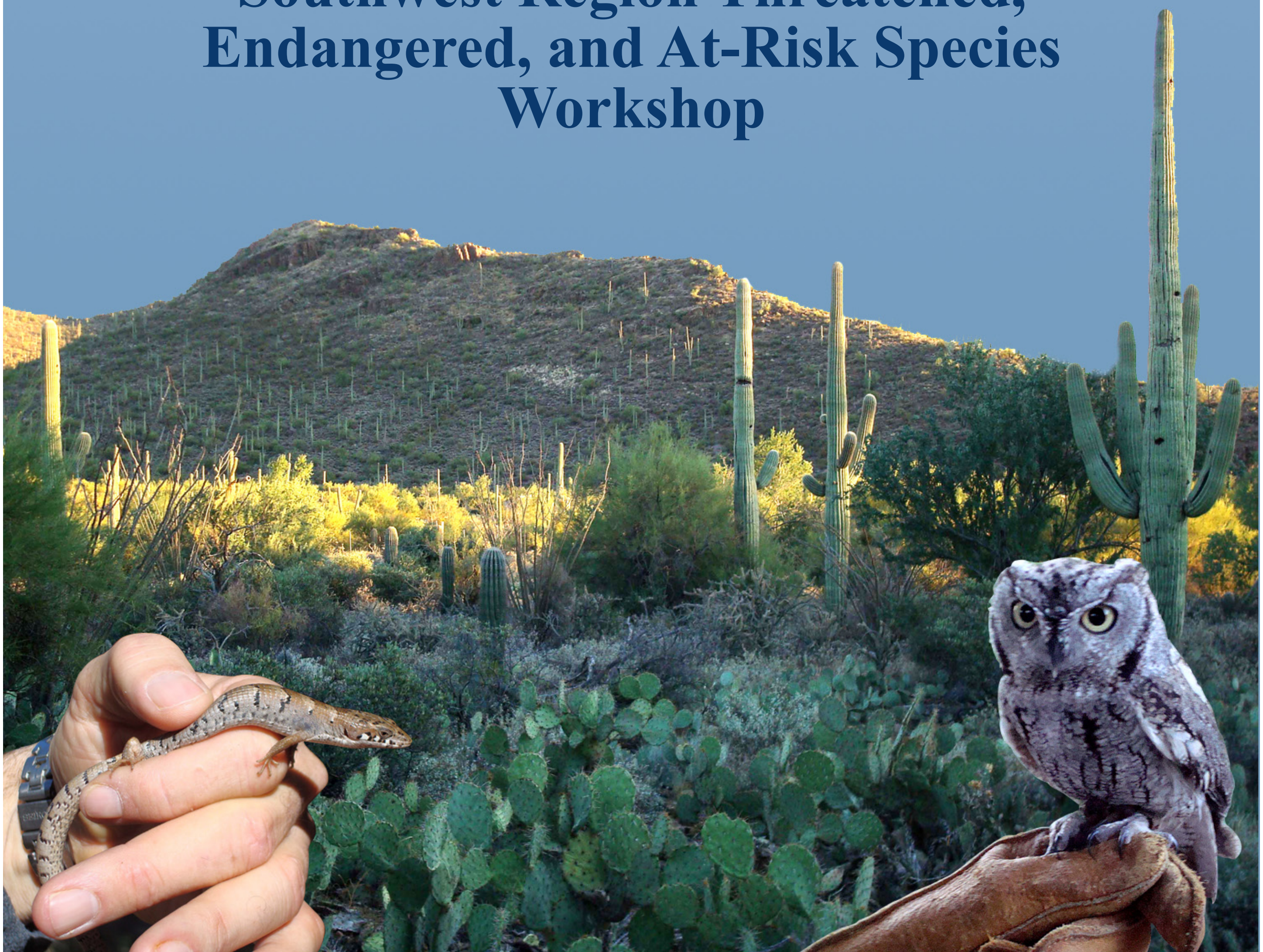
Proceedings from the

Southwest Region Threatened, Endangered, and At-Risk Species Workshop



22-25 October 2007
Tucson, Arizona

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program

ESTCP

Department of Defense Legacy Program

Report Documentation Page					*Form Approved OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE **OCT 2007**		2. REPORT TYPE			3. DATES COVERED **00-00-2007 to 00-00-2007**
4. TITLE AND SUBTITLE **Proceedings from the Southwest Region Threatened, Endangered, and At-Risk Species Workshop**					5a. CONTRACT NUMBER
					5b. GRANT NUMBER
					5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)					5d. PROJECT NUMBER
					5e. TASK NUMBER
					5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Strategic Environmental Research and Development Program (SERDP),Environmental Security Technology Certification Program (ESTCP),4800 Mark Center Drive, Suite 17D08,Alexandria,VA,22350-3605**					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S)
					11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**180**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

FOREWORD

These proceedings encompass outcomes from the Southwest Region Threatened, Endangered, and At-Risk Species (TER-S) Workshop and reflect the opinions and views of workshop participants, not necessarily those of the Department of Defense (DoD). This document is available in PDF format at www.serdp.org/tes/Southwest.

Table 1. Contributing Authors

Name	Organization
Dr. Julio Betancourt	U.S. Geological Survey, Desert Laboratory
Mr. L. Peter Boice	DoD Conservation/Legacy Resource Management Program
Dr. Matthew Brooks	U.S. Geological Survey, Western Ecological Research Center
Ms. Alison Dalsimer	HydroGeoLogic, Inc.
Mr. Sean Donahoe	HydroGeoLogic, Inc. (consultant)
Dr. Todd Esque	U.S. Geological Survey, Western Ecological Research Center
Dr. John A. Hall	DoD Strategic Environmental Research and Development Program (SERDP)/ Environmental Security Technology Certification Program (ESTCP)
Dr. Andrew Hautzinger	U.S. Fish and Wildlife Service
Mr. Timothy Hayden	U.S. Army Corps of Engineers, Engineer Research and Development Center
Dr. Susan Howe	Colorado State University
Ms. Lainie Levick	USDA Agricultural Research Service
Dr. Guy McPherson	University of Arizona
Ms. Valerie Morrill	U.S. Army Yuma Proving Ground
Dr. David Mouat	Desert Research Institute
Dr. Leslie Orzetti	HydroGeoLogic, Inc. (consultant)
Dr. Michael Rosenzweig	University of Arizona
Ms. Alicia Shepard	HydroGeoLogic, Inc.
Dr. Thomas D. Sisk	Northern Arizona University
Dr. Mark Sogge	U.S. Geological Survey, Colorado Plateau Research Station
Dr. Charles Van Riper	U.S. Geological Survey, Southwest Biological Science Center
Dr. Larry Voyles	Arizona Department of Game and Fish
Mr. William Woodson	HydroGeoLogic, Inc. (consultant)

HydroGeoLogic, Inc. supported this workshop and produced the resulting proceedings document through funding awarded by the DoD Legacy Resource Management Program (Huntsville COE contract W912DY-07-2-0007, project 07-377) and the DoD's Strategic Environmental Research and Development Program and Environmental Security Technology Certification Program (contract FA4890-04D-0009, Subcontract DK03).

Recommended Citation: HydroGeoLogic, 2008. Proceedings from the Southwest Region Threatened, Endangered, and At-Risk Species Workshop, 22-25 October 2007, Tucson, Arizona. Prepared for the Legacy Resource Management Program, Strategic Environmental Research and Development Program, and Environmental Security Technology Certification Program by HydroGeoLogic, Inc., Reston, Virginia.

This page intentionally left blank.

EXECUTIVE SUMMARY

The Department of Defense (DoD) is responsible for the management of nearly 30 million acres of land as well as substantial waters and air space used for training Military Service personnel and testing their equipment. In the southwestern United States, the military manages vast areas of land and resources within its installations' boundaries. These installations are critical for military training and testing, provide essential habitat for numerous threatened, endangered, and at-risk species (TER-S), and yet occur in areas with significant concentrations of urban, agricultural, mining, and recreational use that have impacted historic amounts and conditions of aquatic and terrestrial ecosystems on which TER-S depend. To facilitate the recovery of TER-S and to mitigate against the need for new listings, increased attention must be given to TER-S management from both an ecosystem and cross-boundary perspective.

Through a collaborative effort, DoD's Strategic Environmental Research and Development Program (SERDP), Environmental Security Technology Certification Program (ESTCP), and Legacy Resource Management Program (Legacy) sponsored the *Southwest Region Threatened, Endangered, and At-Risk Species Workshop* held 22-25 October 2007 in Tucson, Arizona. This workshop was the third in a planned series of regional TER-S workshops recommended at a June 2005 national symposium addressing TER-S on DoD and adjacent lands.

The specific objectives for the Southwest Region TER-S Workshop were to (1) assess TER-S management needs within a regional context, with an emphasis on system-level and cross-boundary approaches; (2) assess these approaches for their potential to keep common species common while recovering or enhancing TER-S populations; (3) assess current understanding of the ecology of arid and semiarid ecosystems—in terms of understanding the dynamics of highly variable and difficult to predict environments that are also subject to periodic long-term drought—and how that does or should affect management approaches; (4) examine the current state of the practice within DoD for such holistic approaches; (5) identify gaps in knowledge, technology, management, and partnerships that, if addressed, could improve implementation of system-level and cross-boundary approaches; and (6) prioritize DoD investment opportunities to address these gaps. To achieve these objectives, workshop sponsors and organizers assembled a broad spectrum of discipline experts from the research and management communities, including federal and state agencies, academia, and the non-governmental conservation community.

The workshop opened with a plenary session consisting of presentations summarizing the sponsoring programs, DoD's Western Regional Partnership, and commissioned white papers on climate variability and change, fire ecology, the hydrology and ecology of intermittent stream and dry wash ecosystems, and spatial scale and TER-S management.[1] A subsequent tour of Fort Huachuca enabled participants to experience some of the installation's efforts to manage TER-S and their habitats so they could better understand the uniqueness of resources and the challenges of implementing natural resource management on a military installation.

During the two days of workshop discussions, attendees participated in one of three concurrent breakout groups during three sessions focused on the following major themes: (1) TER-S

[1] White papers were provided to participants prior to the workshop and are attached in Appendix E.

Management: Understanding Patterns of Rarity Within an Ecological System Context; (2) Ecological Processes and Their Variability in Space and Time; and (3) Monitoring, Management, and Coordination Across Boundaries. Through the breakout group discussions, participants identified science and management issues related to ecological systems, infrequent large-scale disturbance events, maintaining connectivity amidst land-use and climate change, impacts from upland restoration, and fire effects and dynamics, as well as opportunities to overcome management challenges and strengthen DoD partnerships with federal and state agencies, academic institutions, and non-governmental organizations throughout the region.

This proceedings document summarizes workshop discussions and identifies priority information gaps. All priority needs identified by participants are captured in this document and formed the basis for a further synthesis and prioritization that resulted in the identification of ten top priority needs. These priorities, described in detail in Section 8.0, include:

- Ecological Role of Fire and Causes and Ecological Effects of Altered Fire Regimes in the Southwest
- Impacts and Management of Non-Native Invasive Species in the Southwest
- Management Needs for Overcoming the Impacts of Altered Fire Regimes
- Impacts of Climate Variability and Change in the Southwest
- Impacts of Fragmentation and Habitat Reduction in the Southwest
- Hydrology and Ecology of Southwestern Intermittent Streams, Dry Washes, and Adjacent Riparian Zones
- Understanding Patterns of Species/Population Distributions and Rarity to Support Management
- Providing the Infrastructure Support for Research and Management in the Southwest
- Monitoring the Status of Southwestern Ecological Systems and Species
- Establishing and Implementing Effective Partnerships

SERDP, ESTCP, and Legacy are using workshop discussions and outcomes to help guide their TER-S related investments in the Southwest. Advancing research priorities and using the resulting information to better manage listed and at-risk species offers a significant opportunity to benefit TER-S populations and sustain military training and testing lands. This workshop represents an important step toward a long-term effort for stakeholders to work together to help DoD fulfill its military mission while protecting the valuable resources with which it is entrusted.

Overall, participants gained a better understanding of how fire, invasive species, habitat fragmentation, and other factors exacerbate habitat and species management difficulties, as well as how little is known about dry wash systems. Further, it was suggested that both researchers and managers need to not only focus on efforts to combat the effects of global climate change, but to also learn to adapt to these conditions as the new norm.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page

LIST OF APPENDICES

LIST OF TABLES

Page

LIST OF ACRONYMS

BLM	Bureau of Land Management
BMP	best management practice
BRAC	Base Realignment and Closure
CESU	Cooperative Ecosystem Studies Unit
COE	Corps of Engineers
DoD	Department of Defense
ENSO	El Niño–Southern Oscillation
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
FWS	Fish and Wildlife Service
HRV	historic range of variability
GAO	Government Accountability Office
GCM	general circulation model
GHG	greenhouses gas
GIS	geographic information system
IBI	Index of Biotic Integrity
I&M	inventory and monitoring
INRMP	Integrated Natural Resources Management Plan
IPCC	Intergovernmental Panel on Climate Change
Legacy	Legacy Resource Management Program
LIDAR	Light Detection and Ranging
MRLC	Multi-Resolution Land Characteristics Consortium
NBII	National Biological Information Infrastructure
NEON	National Ecological Observatory Network
NGO	non-governmental organization
NIS	non-native invasive species
NLCD	National Land Cover Database
NPS	National Park Service
NRC	National Research Council
OSD	Office of the Secretary of Defense
R&D	research and development

LIST OF ACRONYMS (continued)

RCM	regional climate model
SERDP	Strategic Environmental Research and Development Program
SERPPAS	Southeast Regional Partnership for Planning and Sustainability
SOP	standard operating procedure
TER-S	threatened, endangered, and at-risk species
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
V/C	[climate] variability and change
WRP	Western Regional Partnership

ACKNOWLEDGEMENTS

The Southwest Region Threatened, Endangered, and At-Risk Species Workshop sponsors wish to thank all the white paper authors, plenary session speakers, and technical session chairs for helping make this event a worthwhile and productive endeavor.

The sponsors extend a special thanks to Sheridan Stone for organizing and leading the field tour of Fort Huachuca; members of the Department of Defense (DoD)/Fish and Wildlife Service (FWS) Science Forum;[2] and the organizers and steering committee members (see table below) who helped formulate the agenda, identify appropriate participants, and determine priorities.

Table 2. Workshop Steering Committee

Name	Organization
Mr. L. Peter Boice	DoD Conservation/Legacy Resource Management Program
Dr. Rick Brusca	Arizona-Sonora Desert Museum
Dr. Ted Cordery	Bureau of Land Management
Dr. Todd Esque	U.S. Geological Survey
Dr. John A. Hall	DoD SERDP/ESTCP
Mr. Steve Helfert	U.S. Fish and Wildlife Service
Dr. Susan Howe	Colorado State University
Ms. Valerie Morrill	U.S. Army Yuma Proving Ground
Dr. David Mouat	Desert Research Institute
Dr. Michael Rosenzweig	University of Arizona
Mr. Russell Scofield	Bureau of Land Management
Dr. Thomas D. Sisk	Northern Arizona University
Dr. Mark Sogge	U.S. Geological Survey

The sponsors also acknowledge the dedicated efforts of individuals from HydroGeoLogic, Inc. (HGL), including Ms. Alison Dalsimer, project manager; Ms. Alicia Shepard, Mr. Sean Donahoe, Dr. Leslie Orzetti, and Mr. William Woodson, session rapporteurs; and Ms. Karole Braunstein, Ms. Kelly Magathan, and Mr. John Thigpen for logistic and onsite support.

Finally, the sponsors wish to thank all the event's participants (see Appendix A), without whom this workshop could not have happened.

Cover Photos: Kelly Magathan

[2] The DoD/FWS Science Forum is a research and development (R&D) working group of the Endangered Species Roundtable – a group of Washington, DC-based policy makers, managers, and others who meet regularly to discuss TER-S-relevant issues. Members include representatives from the U.S. Fish and Wildlife Service (USFWS), DoD, Army, Navy, Air Force, and Marines, as well as the U.S. Forest Service (USFS), Bureau of Land Management (BLM), U.S Geological Survey (USGS), and National Park Service (NPS).

1.0 INTRODUCTION AND BACKGROUND

The Department of Defense (DoD) utilizes nearly 30 million acres of land as well as substantial waters and air space to conduct missions vital to National Security. These areas provide habitat for a great diversity of plants and animals, some of which are found only in areas within DoD stewardship. In all, DoD personnel are responsible for managing 320 threatened and endangered species and nearly 550 species at risk. Through improved understanding of these species, their habitats, and relationships to military training and testing activities, DoD can work with stakeholders to enhance species conservation.

This document presents a summary of results from the Southwest Region Threatened, Endangered, and At-Risk Species (TER-S) Workshop sponsored by DoD’s Strategic Environmental Research and Development Program (SERDP), Environmental Security Technology Certification Program (ESTCP), and Legacy Resource Management Program (Legacy). The workshop took place 22-25 October 2007 in Tucson, Arizona. Workshop outcomes will be used to guide SERDP, ESTCP, Legacy and other interested party TER-S-related research, demonstration, and management investments over the next three to five years.

1.1 WORKSHOP SPONSORS

SERDP is DoD’s environmental science and technology program, planned and executed in partnership with the Department of Energy and the Environmental Protection Agency, with participation by numerous other federal and non-federal organizations. To address the highest priority issues confronting the Military Services, SERDP focuses on cross-service requirements and pursues high-risk/high-payoff solutions to DoD’s most intractable environmental problems. SERDP’s investments range from basic research through applied research to exploratory development needs in the areas of Environmental Restoration, Munitions Management, Sustainable Infrastructure, and Weapons Systems and Platforms. SERDP’s Sustainable Infrastructure initiative supports research and development (R&D) efforts to (1) sustain the use of DoD’s lands, estuaries, oceans, and air space; (2) protect its valuable natural, cultural, and built infrastructure resources for future generations; (3) comply with legal requirements; and (4) provide compatible multiple uses of its resources.

ESTCP is DoD’s environmental technology demonstration and validation program. ESTCP seeks to promote the use of innovative, cost-effective environmental technologies that target DoD’s most urgent environmental needs, including range sustainment, through demonstrations at DoD facilities and sites. ESTCP selects lab-proven technologies with broad DoD application for rigorous field trials. These demonstrations document the cost, performance, and market potential of the technology. ESTCP technology demonstrations address DoD environmental needs in the Environmental Restoration, Munitions Management, Sustainable Infrastructure, and Weapons Systems and Platforms focus areas. These technologies provide a return on investment through improved efficiency, reduced liability, and direct cost savings, while enhancing military readiness. Successful technologies supported by ESTCP often have commercial applicability.

Legacy provides DoD funding to efforts that conserve and protect the nation’s natural and cultural heritage. The program assists DoD in protecting and enhancing resources while supporting military readiness. Three principles guide the Legacy Program: stewardship,

leadership, and partnership. Stewardship initiatives assist DoD in safeguarding its irreplaceable resources for future generations. By embracing a leadership role as part of the program, DoD serves as a model for respectful use of natural and cultural resources. Through partnerships, Legacy strives to access the knowledge and talents of individuals outside of DoD. This is accomplished through the funding of management-oriented projects that support one or more of the 12 areas of emphasis, including Readiness and Range Preservation, Cooperative Conservation, Invasive Species Control, and Regional Ecosystem Management.[3]

Through the conservation aspects of these three programs, SERDP, ESTCP, and Legacy help DoD maintain its dual missions of readiness and environmental stewardship. Research and development initiatives begun in SERDP may need to be validated through ESTCP and later implemented via Legacy. Likewise, on-the-ground management funded by Legacy may uncover basic R&D needs for future investment through SERDP and ESTCP. Ultimately, the three programs offer an integrative method of utilizing DoD funding to foster natural resource management.

1.2 JUNE 2005 SYMPOSIUM AND WORKSHOP ON TER-S ON DoD AND ADJACENT LANDS

In June 2005, the U.S. Army Corps of Engineers (COE) Engineer Research and Development Center (ERDC), SERDP, Legacy, and other federal and non-federal partners sponsored a national symposium to examine issues related to TER-S on DoD and adjacent lands. The objectives were to:

- present the most up-to-date information on government and academic TER-S research relevant to DoD,
- stimulate collaboration and foster partnerships among participants, and
- identify additional areas of research needed to address TER-S and associated habitat issues facing DoD and other federal land-managing agencies.

Participants included nearly 200 researchers and managers from DoD, all the Military Services, the U.S. Fish and Wildlife Service (USFWS), National Park Service (NPS), U.S. Geological Survey (USGS), U.S. Department of Agriculture (USDA), and various non-profit organizations, state agencies, universities, and private consulting firms. Findings from this event are described in a proceedings document, available at http://www.serdp.org/tes/National/.

The following high-priority TER-S needs were identified at the Symposium and Workshop:

- ***Conduct research on basic species life history and improve biological information***. There is a serious lack of basic biological information for many listed and at-risk plant and animal species. Only through a clear understanding of the species and the stressors that directly impact population health and viability can suitable management protocols be developed.

---

[3] See www.dodlegacy.org for more information on the *Areas of Emphasis* and www.denix.osd.mil for the program's monthly newsletters, *Natural Selections* and *Cultural Resources Update.*

- ***Increase proactive conservation efforts for species at risk***. When considering the threats to already listed and at-risk species, it is evident that additional resources must focus on proactive conservation measures to prevent additional species listings. Research is needed to properly and fully evaluate the cost-benefits associated with proactive (versus reactive) conservation efforts, especially with respect to the impacts of non-native invasive species (NIS). Knowledge gained could then be used to implement appropriate policies and funding initiatives to conserve resources in the long-term.
- ***Develop more consistent peer-reviewed data standards and monitoring protocols***. Monitoring protocols, guidelines, and indicators are not fully developed for many TER-S. Additionally, in cases where protocols exist, they do not necessarily provide meaningful data for decision makers. Therefore, research is needed to develop protocols. This must be done using a rigorous scientific approach and peer review process that incorporates how data are to be collected, managed, analyzed, and reported to ensure efficient collection of data elements directly relevant to key management decisions.
- ***Improve predictive models to support management decisions***. To manage and conserve TER-S habitat at a regional scale, land managers must apply a complex suite of management measures across a wide landscape in coordination with other regional landowners to achieve ecosystem goals. While several pilot projects have been completed, additional research is needed to refine, validate, and expand these predictive modeling efforts.
- ***Improve information sharing among stakeholders***. Funds available for monitoring and conserving listed species are limited, with no one organization having the ability to collect all of the necessary data or to fully implement regional conservation restoration measures. It is important to be able to leverage conservation-related information and actions across agencies and in partnership with private initiatives. Through the development and application of new technologies based on collaboration, it may be possible for TER-S conservation organizations and partners to yield significantly enhanced results.
- ***Focus on protection of endangered ecosystems rather than individual species***. There is a need to focus TER-S conservation efforts on the protection of "endangered ecosystems" at a regional scale, rather than managing the biological needs of single species. Research is needed to develop more sophisticated regional management tools and approaches.

Further, it was determined that TER-S issues are fundamentally regional in nature. For example, the decline of Pacific salmon is no more an issue in Illinois than the decline of the desert tortoise is in New Jersey. In response and to help further refine and implement the 2005 Symposium and Workshop results, SERDP, ESTCP, and Legacy developed a plan to host a series of regional TER-S workshops. Symposium and Workshop participants specifically identified the need for workshops in the following four prioritized regions: Pacific Islands, Southeast, Southwest, and Northwest.[4] Boundaries for the four identified regions were to be determined by location of

[4] At this time, there are no plans to conduct a joint SERDP-ESTCP-Legacy TER-S workshop in the Northwest.

military installations and key ecological features, rather than on existing but artificial agency boundary determinations.

1.3 SOUTHWEST REGION

The Southwest was identified at the 2005 Symposium and Workshop as the third highest priority region based on the number of imperiled species and the imminence and magnitude of various threats to them. For the purposes of this workshop, "Southwest" was defined as encompassing the Chihuahuan, Mojave, and Sonoran deserts, the basin and range transition between the Sonoran and Chihuahuan deserts (semidesert grasslands and sky island woodlands), and embedded intermittent and permanent aquatic/riparian ecosystems.

Within this region, DoD is responsible for managing numerous installations and ranges with the eleven largest (i.e., greater than 50,000 acres) encompassing a cumulative land area in excess of 8.8 million acres. DoD's southwestern land holdings harbor more than 100 TER-S, including the Sonoran pronghorn (*Antilocapra americana sonoriensis*), desert pupfish (*Cyprinodon macularius*), Lane Mountain milk-vetch (*Astragalus jaegerianus Munz*), and desert tortoise (*Gopherus agassizii*). Protecting these species and the habitats on which they depend is crucial to sustaining training and testing capabilities within the region.

2.0 APPROACH

The stated objectives for the Southwest Region TER-S Workshop were to:

- Assess TER-S management needs within a regional context, with an emphasis on system-level and cross-boundary approaches;
- Assess these approaches for their potential to keep common species common, while recovering or enhancing TER-S populations;
- Assess current understanding of the ecology of arid and semiarid ecosystems—in terms of understanding the dynamics of highly variable and difficult to predict environments that are also subject to periodic long-term drought—and how that does or should affect management approaches;
- Examine the current state of the practice within DoD for such holistic approaches;
- Identify gaps in knowledge, technology, management, and partnerships that, if addressed, could improve implementation of system-level and cross-boundary approaches; and
- Prioritize DoD investment opportunities to address these gaps.

2.1 STEERING COMMITTEE

Invitations were extended to representatives from the various sectors of the endangered species management and research communities to act as a steering committee for the Southwest Region TER-S Workshop. Thirteen people, including federal, state, and NGO representatives, participated in this committee, whose purpose was to act as an information source and guiding force for agenda development. Specifically, members were asked to help define the scope of the workshop, recommend session and white paper topics, and help identify appropriate workshop participants and session chair candidates.

2.2 READ-AHEAD MATERIALS

To prepare participants for the workshop, a variety of read-ahead materials were provided. These included general information about military natural resource activities in the region, information about the sponsoring agencies, and a workshop charge (Appendix C) that described the event's goals and objectives. Additionally, breakout group chairs were provided charges specific to their session (Appendix D), and all participants were provided white papers (Appendix E) relevant to breakout group discussions. White paper topics included *Climate Variability and Change in the Southwest*; *Fire Regimes of the American Southwest; Hydrology and Ecology of Intermittent Stream and Dry Wash Ecosystems*; *Spatial Scale and the Management of Threatened/Rare/Endangered Species*; and *Military Land Use: Overview of DoD Land Use in the Desert Southwest, Including Major Natural Resource Management Challenges*.

2.3 PARTICIPANTS

Based on DoD/FWS Science Forum, steering committee, and organizer input, the sponsors invited local and headquarters-level representatives from all of the Military Services, a balance

of federal and non-federal field managers, academic researchers, state natural resource personnel, and representatives from various local conservation organizations. Participants represented a diverse group of disciplinary experts who could provide the broad technical basis for input to DoD's out-year research, demonstration, and management agenda for TER-S conservation in the Southwest region. In the end, 68 individuals participated in the workshop.

2.4 AGENDA ELEMENTS

In developing the agenda (Appendix B), the steering committee wanted to ensure that participants were given sufficient background information regarding the state of management and science relevant to DoD TER-S in the Southwest to engage in informed and productive working group discussions. To help achieve this goal, the plenary session was structured to include presentations from the workshop sponsors, an overview of DoD's Western Regional Partnership (WRP) Initiative, and summaries of four of the commissioned white papers. Further, to familiarize participants with natural resource management activities on military installations, a field tour of Fort Huachuca was arranged. Following the plenary and field tour, the workshop comprised two days of concurrent working group sessions in which participants identified and prioritized relevant information. Following the formal workshop, session chairs, speakers, and organizers met to discuss workshop results and propose recommendations.

2.5 FORMATION OF BREAKOUT GROUPS

The primary objective for this workshop was to develop a prioritized management and research agenda for TER-S in the Southwest region. Participants were asked to discuss the state of the science for TER-S as a basis for determining gaps in current scientific knowledge, identify and roughly prioritize needs, and develop the initial design for a research and management agenda. To accomplish this, attendees participated in three of the nine topical breakout groups. Table 3 illustrates how the workshop discussions and focus areas were organized.

Table 3. Southwest Region TER-S Workshop Breakout Groups

SESSION NAME	BREAKOUT GROUP 1	BREAKOUT GROUP 2	BREAKOUT GROUP 3	BREAKOUT GROUP 4
TER-S Management	Desert Scrub	Semi-Desert Grasslands and Chihuahuan Desert	Woodlands (Sky Islands)	Intermittent Streams and Dry Washes
Ecological Processes	Fire Regimes	Climate Variability and Change	Fragmentation	Hydrology and Ecology
Monitoring, Management, and Coordination	Effects of Spatial Scale	Regional Condition Metrics	Hierarchical Monitoring	Partnerships and Information Sharing

3.0 ESTABLISHING A COMMON GROUND

The first day of the workshop was devoted to providing attendees with background and contextual information. The workshop began with introductions and program summaries by Dr. John A. Hall of SERDP/ESTCP and Mr. L. Peter Boice of DoD Conservation/Legacy. Dr. Hall and Mr. Boice also detailed the workshop's goals and expected outcomes. These were followed by a presentation on DoD's Western Regional Partnership initiative and summary presentations of four of the commissioned white papers. A subsequent tour of Fort Huachuca enabled participants to view firsthand some of the installation's efforts to manage TER-S and their habitats so they could better understand the uniqueness of the resources and challenges of implementing natural resource management on a military installation.

3.1 REGIONAL CHALLENGES AND OPPORTUNITIES

The sponsors agreed that it was important to establish a foundation of common understanding among all participants. To achieve this, they commissioned a series of informational white papers (Appendix E), which were available as read-ahead materials prior to the workshop. These white papers formed the basis for several presentations during the Plenary Session.

3.1.1 DoD Western Regional Partnership Initiative – Ms. Amy Duffy

Recently, to address many of its land management issues, DoD has focused on "outside the fence line" issues. The result is an increasingly regional focus, as many land use processes are driven by factors well beyond any one installation's immediate vicinity. To maximize the effectiveness of its efforts, DoD has initiated and participated in several national and regional partnerships, including with local governments (e.g., National Association of Counties), state legislatures (e.g., National Conference of State Legislatures), land trust alliances (e.g., Land Trust Alliance), multi-stakeholder sustainability and land use planning groups (e.g., Northwest Florida Greenway Project), and other initiatives (e.g., Southeast Regional Partnership for Planning and Sustainability [SERPASS]). Benefits from these regional partnerships include:

- Gaining different perspectives and new ways of doing business and solving problems;
- Providing forums to link efforts with other stakeholders within the region;
- Enhancing community-driven planning and compatible land use;
- Sharing GIS and decision-support information between stakeholders;
- Participating in regional broad-based conservation efforts; and
- Working with interested parties to protect rural landscapes and working lands.

DoD is now helping to form a new regional partnership initiative in the West—the DoD Western Regional Partnership.[5] In the Southwest, WRP is being initiated as a regional partnership between DoD and other federal agencies as well as state and Tribal executive leadership in the states of Arizona, California, Nevada, New Mexico, and Utah. Key issues to be addressed by this

[5] An overview of the WRP was provided at the workshop, but an informational white paper was not developed.

initiative include water resources, development and encroachment, cleanup activities, air quality, fire management, TER-S, habitat restoration (including strategies for combating invasive species), climate change, energy, wildlife corridors, and border issues. The WRP will provide a forum for key stakeholders to work proactively and collaboratively at multiple levels to facilitate better planning and a sustainable future for all in the Southwest.

3.1.2 Variability in Southwest Precipitation – Dr. Julio Betancourt

Climate variability and change (V/C) pose significant challenges to land and resource managers. This presentation focused on (1) patterns of decadal-to-decadal scale precipitation variability and its association with global sea surface temperatures (temperatures in the upper meter of the ocean) and (2) recent findings on how climate change might affect both temperature and precipitation in the Southwest. Researchers have found definitive clustering patterns of drought and wet periods in the Southwest, which can be linked in part to changes in multi-decade scale oscillations in oceanic temperatures in the Atlantic (the foremost principal component) and the Pacific. These relationships are further substantiated by significant research in historic fluctuations using proxy variables such as tree ring size and ice core data. Overall, it appears that small increases in global temperatures in the coming decades have the potential to significantly increase the incidence of drought periods, temperature variability, and the incidence of fires in the Southwest. Land managers will need to take into account these factors when addressing long-term regional landscape issues. Furthermore, the relationships developed through this research may serve to better predict near-term drought or wet periods for the region when scheduling large-scale DoD training or initiating land management projects that may be sensitive to climatic conditions.

3.1.3 Altered Fire Regimes – Dr. Matthew Brooks, Dr. Guy McPherson

Fire regimes in many ecosystems of the southwestern United States have changed substantially coincident with Anglo settlement. In some desert shrublands, the incidence of fire has increased with increased fuelbed flammability following the invasion of non-native grasses. In most other areas (e.g., desert grasslands, woodlands, and lower elevation forest), fire has become less prevalent due to suppression efforts, removal of fine fuel by livestock, development resulting in fragmentation of formerly continuous fuels, and other anthropogenic factors. In addition, global climate change is contributing to regional warming and altering precipitation patterns, helping to exacerbate the spread of non-native grasses throughout the region. As a consequence of these factors, fire extent and intensity are likely to increase in most of the region's ecosystems. Of particular concern is the increased potential for widespread stand replacement, which occurred during the high intensity fires of the medieval warm period.

Local and regional land managers have initiated many programs to mitigate the adverse effects associated with altered fire regimes; however, the ramifications of these programs are not well understood. For example, a prescribed burn during certain time periods may do more harm than good to native vegetation. Furthermore, fire management techniques that work well in one location may not necessarily work well in another because of compounding variables (e.g., elevation, available fuel) that may require a customized approach. Thus, further research is needed to better understand the interactions between environmental variables that affect fire

regimes and the proper approaches for designing effective fire management programs given local conditions.

3.1.4 Hydrology and Ecology of Intermittent Stream and Dry Wash Ecosystems – Ms. Lainie Levick

Ephemeral and intermittent streams make up approximately 59% of all streams in the United States (excluding Alaska) and more than 81% in the arid and semi-arid Southwest (Arizona, New Mexico, Nevada, Utah, Colorado, and California) according to the National Hydrography Dataset. They are often the headwaters or major tributaries of most perennial streams in the Southwest and make up 94% of stream miles in Arizona. Given their vast extent, ephemeral and intermittent streams are crucial to the overall health of a watershed and provide a wide array of functions, including forage, cover, nesting, and movement corridors for wildlife. Because of the relatively higher moisture content in dryland streams, vegetation and wildlife abundance and diversity is higher than in the surrounding uplands. Ephemeral and intermittent streams provide the same hydrologic functions as perennial streams by moving water, nutrients, and sediment through the watershed. When functioning properly, dryland streams or “dry washes” provide many of the same services as perennial riparian-wetland areas, such as landscape hydrologic connections; stream energy dissipation during high-water flows that reduces erosion and improves water quality; surface and subsurface water storage and exchange; groundwater recharge and discharge; sediment transport, storage, and deposition aiding in floodplain maintenance and development; nutrient cycling; wildlife habitat and movement/migration; support for vegetation communities that help stabilize stream banks and provide wildlife services; and water supply and water-quality filtering.

Ecologically sustainable land and wildlife management requires a landscape or watershed-scale approach to ecosystem protection and would be meaningless and ineffective if these intermittent streams are significantly degraded. Yet, very little is known about these systems. Ironically, they are too often viewed as already “degraded” because of their appearance during dry periods. However, during wet periods, the biodiversity of these systems is just as high as perennial streams. Because of their importance to wildlife and the overall watershed, more research and monitoring are needed on the ecological and hydrological interactions of these systems.

3.1.5 Spatial Scale and the Management of Threatened/Rare/Endangered Species – Dr. Michael Rosenzweig

It is important for land managers to consider that different processes operate at different spatial scales. The key question is how processes at different scales interact and whether knowledge of such interactions, combined with habitat manipulation, promise to better secure the future for TER-S. With respect to spatial scale, there is common agreement about its general structure, but the processes that operate at various scales, their influence, interaction, and relative importance to a particular species are complex and often not well understood. Further, such processes are scale-dependent, adding to the complexity of the system. In addressing such unwieldy complexity, it is important to consider and prioritize what a particular species needs from its habitat to feed and breed, including inter-ecological interactions and migratory issues. To generalize, available data suggests that there is a linear relationship between biodiversity and available habitat. Thus, as a general goal for land managers, it is important to redeem and

preserve as much available habitat as possible to protect biodiversity. Better understanding and management of the needs of individual species (including basic natural history) and preservation of ecosystem function is important to ensure harmonious coexistence between human use of the land and achieving natural resource management objectives.

Reconciling joint use of the land has been a point of emphasis within DoD that could be replicated beyond its borders. This reconciliation needs to occur at multiple scales; therefore, it is important for local land managers to think, manage, and act beyond political boundaries and at multiple scales, from large-scale global issues to the very small microhabitat requirements of individual species. Researching, understanding, and managing these key stressor points and/or deficiencies will be important for ensuring long-term success in protecting individual TER-S as well as overall biodiversity.

3.1.6 Military Land Use: Overview of DoD Land Use in the Desert Southwest, Including Major Natural Resource Management Challenges – Mr. Timothy Hayden

DoD military land use of the desert Southwest includes a wide spectrum of military weapons testing, force-on-force training, and various types of flight training. The desert Southwest provides a critical asset for the U.S. military—open space. Installations in the Southwest tend to be much larger than installations in other regions of the nation, with several in excess of one million contiguous acres. This open space has allowed the military to conduct unique types of testing and training and to define expansive air maneuver regions above its own ranges as well as the vast public lands of other agencies. Highly variable training and testing activities can thus be conducted in a three-dimensional land/air space situation that replicates modern battle space.

Overall, the desert regions of the Southwest are a critical asset to the U.S. military, in part because this area offers environments that are analogs to similar environments throughout the world where the military operates. Natural resource management challenges include the large spatial extent of lands and air space under DoD management, highly variable military land use requirements, significant endangered species regulatory and conservation requirements, encroachment and Base Realignment and Closure (BRAC) constraints, competition for water resources, and climate change. DoD natural resource managers must continue to meet these challenges through inter-agency cooperative agreements, integrated natural resource management plans, and DoD sustainable range programs.

3.2 FIELD TOUR OF FORT HUACHUCA

Fort Huachuca is an Army installation located near Sierra Vista, Arizona. Its primary mission is Military Intelligence Training and Doctrine, with additional missions of communications management, electronics testing, and unmanned aerial vehicle training. More than 25 tenants use the installation for various military missions, including Air Force and Arizona National Guard fighter jet training, a unique advanced airlift tactical training center, and soldier training at elevations ranging from 4,000-8,600 feet above sea level. The installation is located in the Chihuahuan Desert and contains about 72,960 acres with an annex of approximately 26,880 acres at Willcox Playa. Water conservation and the nearby San Pedro River are major focus areas for Fort Huachuca. The installation also has four federally listed species onsite—Sonoran tiger salamander (*Ambystoma tigrinum stebbinsi*), lesser long-nosed bat (*Leptonycteris yerbabuenae*),

Huachuca water umbel (*Lilaeopsis schaffneriana* var. *recurvata*), and Mexican spotted owl (*Strix occidentalis lucida*).

Welcome Address: The first stop on the tour featured a welcome address from the installation's Public Affairs Officer. Conservation highlights of this address included water conservation, protection of agave for the lesser long-nosed bat, and habitat management for Mexican spotted owl at higher elevations. Water conservation is necessary to support the military and civilian population in the area and integral to the protection of habitat for the Huachuca water umbel and Sonoran tiger salamander on the installation as well as for southwestern willow flycatcher (*Empidonax traillii extimus*) habitat in the adjacent San Pedro River riparian area. The Army Compatible Use Buffer program has been used to purchase easements that slow development and land-use change so as to conserve water.

Hummingbird Monitoring: Adjacent to the park-like setting of the welcome address, the group learned about the installation's Hummingbird Monitoring Network.[6] Dr. Susan Wethington, a group founder, demonstrated the capture, data collection, banding, and release of hummingbirds. Because it offers significant suitable habitat, Fort Huachuca serves as a long-term monitoring site for this program, which seeks to understand the population biology and migration of hummingbirds in order to conserve them and their habitat.

San Pedro Valley Vista: This stop provided the group a view of the landscape and geography of Fort Huachuca, focusing specifically on the impacts of area development. Concerns about area development led Fort Huachuca to participate in an alternative futures study, the results of which depicted various likely patterns of development into the 21st century (Steinitz et al., 2003). As a result, installation personnel have partnered with the Bureau of Land Management to monitor the region's imperiled species and to protect the San Pedro River Basin.

Range Road: The drive along Range Road enabled the group to observe military training ranges in savannah and woodland area. Fire is used principally for risk reduction on ranges, but ecological use of fire has evolved over the years. Fort Huachuca has only recently begun to use large-scale ecological fires in grasslands.

Garden Canyon: The same underground springs that feed this canyon are in large part responsible for the high biological diversity in the Huachuca Mountains. The Garden Canyon provides habitat for the Huachuca water umbel, Huachuca spring snail (*Pyrgulopsis thompsoni*), a candidate species, and the world's only known population of Lemmon's fleabane (*Erigeron lemmonii*), also a candidate species. Healthy upland forest conditions are important for maintaining these riparian systems, and though fire and vehicle traffic both adversely impact upland forest conditions, the single largest threat to the riparian system is regional overuse of water resulting from off-installation population growth.

Lower Garden Canyon: Here, the role of fire in managing oak woodland habitat was discussed, as was Fort Huachuca's attempts to thin and prune to reduce the vertical fuel ladder and open the forest canopy. This program is new, and more research is needed on responses to over- and under-story treatments before benefits can be properly assessed. Fire demonstration projects are

[6] See www.hummonnet.org for more information.

needed in woodland areas to develop measures of success and to determine impacts on habitat for species such as the Mexican spotted owl and Gould's turkey (*Meleagris gallopavo Mexicana*). Challenges to utilizing fire more extensively include budget limitations, fire risk, fire control assets, and coordination at large scales.

South Range: During this stop, the group discussed invasive plants, sensitive species, and fire regimes in grassland systems. The invasive Lehmann lovegrass (*Eragrostis lehmanniana*) increasingly occupies Huachuca's ranges, probably because the lands are burned frequently. The lovegrass causes changes in grassland fuel load and fire behavior, which may impact the native agave. Although the impacts of fire on agave are not well understood, it is known that diverse agave age structure is important to ensure annual blooming agave, which is essential to foraging lesser long-nosed bats. Thus, the lovegrass may have negative impacts on this endangered species.

4.0 SESSION 1: TER-S MANAGEMENT: UNDERSTANDING PATTERNS OF RARITY WITHIN AN ECOLOGICAL SYSTEM CONTEXT

Rarity results from processes that occur in the natural environment (e.g., climate change, competition, invasion of exotic species). Some rarity is natural. That is, some species are commonly rare and adapted to be rare. Species may be rare as a consequence of unique biology or in response to anthropogenic influences. In the Southwest, aridity and its variability over space and time, especially in the context of climate change, create unique challenges for managing naturally rare species. This situation exacerbates other existing system stressors, such as habitat loss, alteration of ecological processes, and the introduction of invasive species. Many of the causes and situations that create undesirable rarity are extremely time-dependent and require immediate action. In this session, participants divided into the following breakout groups: *Desert Scrub (Mojave and Sonoran Deserts; Little Grass; Includes Relict Desert Grasslands); Semidesert Grasslands (Invaded by Shrubs) and Chihuahuan Desert; Woodlands (Sky Islands);* and *Intermittent Streams and Dry Washes (Hydrologic Pulse Driven Systems).* The desired outcome for the session was for participants to identify information needs relevant to TER-S management within an ecological system context as it applies to each of the above ecosystem divisions.

4.1 DESERT SCRUB

Chair: Larry Voyles, Arizona Department of Game and Fish

Rarity in desert scrub can be approached from an ecosystem perspective, but species-specific issues also need attention. This breakout group prioritized data gaps and management responses in five categories—landscape-scale; monitoring, indicators, and inventory; habitat/biology; invasive species and fire; and partnerships. Below is the prioritized list of identified needs for understanding patterns of rarity in desert scrub habitats:

- ***Improve understanding of the effects of, and management responses to, disturbances in desert ecosystem processes/structures***, including ecosystem resiliency to disturbances. Examples include how to mitigate increased fire in desert scrub, how desert scrub is being invaded by grasses and weedy forbs, and the impact of invasives on the function of the desert scrub system.

- ***Coordinate long-term research and monitoring both spatially and methodologically.*** Evolve, standardize, and coordinate monitoring protocols among entities. Efforts should be integrated with the National Ecological Observatory Network (NEON)[7] and other initiatives. Monitoring should have the capability to address specific research or management questions (e.g., effects of anthropogenic actions). Also, efforts are needed to assess decadal and multi-decadal population fluctuations and their causes.

[7] From www.neoninc.org/, "NEON is a continental-scale research platform for discovering and understanding the impacts of climate change, land-use change, and invasive species on ecology."

- ***Establish a basic understanding of biophysical linkages in desert scrub systems***. Information is lacking on the biological and physical elements and interrelationships that influence rarity, including soil crusts, soil dynamics, soil disturbance, role of pollinators, role of invasives, and role of groundwater (including the unsaturated zone). Research is also needed to improve the understanding of species-area relationships and distributions.

- ***Identify indicator species for the desert scrub system***. Indicator species can provide a standardized way to measure or detect change and to determine if that change is significant.

- ***Increase species populations on DoD cantonment areas*** (e.g., industrial, housing, office areas) in an effort to keep common species common. DoD installations tend to discount cantonment areas in the management of natural resources. These areas, however, can serve as significant habitats, as observed for hummingbirds at Fort Huachuca. Research is needed on cantonment area capacity to support natural habitats in the context of desert scrub with the goal of increasing dispersal of rare species.

- ***Develop management schemes for invasive plant species***. Research is needed to understand the impacts of NIS, how to monitor NIS populations, and how to manage them. It is especially important to be able to assess the impact of NIS on scrub habitat conversion to desert grassland.

- ***Develop ways to minimize the impact of wildfire on desert scrub, particularly the invasion of grasses after fire***. Efforts are needed to understand how to strategically use landscape features to mitigate the impacts of fire (e.g., assessment of the use of grazing to create firebreaks). The restoration of burned areas also needs attention. What are the impacts of fire on microbes, soil, and native plants? What role may hybrid plants play in restoration?

- ***Develop research partnerships***. Identify and resolve institutional and agency barriers to sharing information and improving communication. There is a need to improve the linkage between academia and management; it is important to improve outreach to on-the-ground biologists. Technologies need to be shared. There also is a need to understand and execute the transition between single-agency and multi-agency research and management, which will require, at a minimum, a way to share or pool funds.

Breakout group discussion generated more than 50 needs, ideas, or initiatives. In addition to the top priority needs outlined above, additional suggestions included:

- ***Characterize the seed bank in desert scrub***. Seed banking may be significant for the rehabilitation of desert scrub lands. Techniques or approaches to describe the seed bank availability for desert plants are needed. This effort would also include understanding life history traits of desert plants.

- ***Synthesize data to assist land managers with habitat restoration/management***. A written compendium of landscape-scale issues and management actions would provide a regional management handbook based on current scientific information. It could be in the form of a landscape-scale plan for management of issues (e.g., invasive species). Such a document must acknowledge that management techniques are dynamic and must evolve as the science evolves.

- ***Obtain basic species inventories by biogeographic boundaries***. Knowing where rare plant and plant communities are is a significant gap. Bringing experts together through a workshop would result in a map of species distribution, gaps, and the elements that drive rarity.

- ***Improve spatial modeling***. The full extent of the distribution of populations is not known. Modeling the locations of plants and plant populations would enable on-site research to be located appropriately by issue.

- ***Create and test models to identify and prioritize stressors that impact species rarity***. Conceptual models for identifying the stressors affecting species rarity need to be tested to help determine how and where to focus our limited resources for TER-S conservation.

- ***Improve understanding of the role of climate change***. A regional monitoring system for climate change should be developed. This would involve regional agreement on the indicators of climate change and an integrated regional monitoring effort of those indicators. Using such a system, the impact of climate change on patches of habitat and patterns of endemism may be studied in addition to linkages between climate change and other stressors affecting species diversity. Research is needed to understand how climate change and anthropogenic stressors affect rarity.

Ideas mentioned but considered of lower priority included:

- Define rarity in the context of space and time (i.e., define a reference point).
- Develop species-specific information for the Sonoran pronghorn and lesser long-nosed bat.
- Improve understanding of core and peripheral populations.
- Improve understanding of the impacts of natural competitive interactions.

4.2 SEMIDESERT GRASSLANDS AND CHIHUAHUAN DESERT

Chair: Mark Sogge, U.S. Geological Survey

This breakout group identified three key categories of research to better understand patterns of rarity within an ecological system context—increase basic knowledge and understanding of

TER-S, communities, and systems; increase understanding of the underlying ecological processes that support TER-S; and develop proactive forecasting tools that allow land managers to better evaluate the impact of an array of factors for adaptive management purposes. Below is the prioritized list of identified needs:

- ***Link research to management activities that are already occurring or planned***. Currently many federal agencies are engaged in large-scale active land management (e.g., BLM is utilizing fire and Tebuthiron treatment to control shrub invasion in large grassland areas), yet little if no research has been done to determine if these techniques are effective in achieving the desired outcome. Furthermore, information is not available to adjust the management and treatment regimes to increase effectiveness through adaptive management. As a top priority, participants identified the need to research these and other land management activities, leveraging ongoing programs across federal agencies, to increase the effectiveness of ongoing land management measures and to share lessons learned across agencies engaged in similar efforts throughout the region. Key aspects of such research should include monitoring (before and after), tools to integrate research results into management actions (adaptive management), and linking localized research on effectiveness to regional efforts.

- ***Develop tools for "evidence-based conservation" or adaptive management (database or other tools)***. Land managers lack a common place to share lessons learned. As a result, the same mistakes often are repeated. A database or other mechanism is needed to share lessons learned relative to regional land management efforts and thus form the basis for "evidence-based conservation" in the Southwest.

- ***Gather basic/baseline information for future comparisons (distribution and composition)***. Insufficient basic knowledge exists regarding how key regional systems are changing over time. There is a need to conduct basic research and collect baseline information on key elements, including relative abundance, age structure, basic demographics, and plant community structure (range, cover for key flora that are present). Only in this way can scientists track the effects of climate change and management decisions.

- ***Develop information and tools to forecast the spread of NIS***. A suite of tools is needed to forecast regional landscape conditions relative to various threats and management regimes, especially NIS. Indictors must be integrated into management regimes.

- ***Identify other species of concern (i.e., what else is rare now, what may become rare in the future)***. At the species level, information is needed to develop a common list of species of concern for the Southwest. It was recognized that the U.S. Fish and Wildlife Service (USFWS), state agencies, and non-governmental organizations (NGO) all have different species lists and that these tend to drive their respective research and management efforts in potentially uncoordinated ways. Further, many species with the potential to become rare/listed in the future

lack attention. To that end, a comprehensive list of species of concern needs to be identified to assist land managers with prioritizing resources, especially in light of impending threats to the Southwest (e.g., global climate change, invasives).

Additional but lower-ranked research topics identified by breakout group participants included:

- Develop forecasting tools to predict:
  - urban growth footprints and curves at the regional scale, as well as impacts to species;
  - regional stressors and effects that would enable identification of appropriate regional partnerships;
  - regional impacts of various water-related issues;
  - fragmentation and habitat loss at the regional scale; and
  - impacts of various management actions, and be able to integrate effects for adaptive management and model calibration.

- Describe and map thresholds between and among key ecosystems (e.g., type conversions from grassland to shrubs).

- Conduct species-specific research on:
  - Baird's sparrow (*Ammodramus bairdii*) wintering habitat conservation;
  - Sonoran pronghorn movement, fragmentation, and permeability issues; and
  - wildlife corridors for medium-sized to large mammals (permeability to enable dispersal).

- Determine the appropriate scale of metrics for managing and monitoring plant community systems (key species, associations, communities) to ensure viable systems and for baseline information on what is now common and rare.

- Determine the effect that scale has on management outcomes and effectiveness (e.g., distributing treatment across large versus small blocks).

- Conduct retrospective studies to evaluate the effectiveness of past management and research studies, relative to the questions outlined above, and investigate the appropriateness of scaling up local/small studies (research, management, monitoring, and policy initiatives) for application at a regional and/or national scale.

- Identify and overcome/improve policy mechanisms and barriers that impede cohesive management of ecosystems.

- Examine the utility of existing high technology tools (GIS, satellite imagery, aerial photography analysis) for assessing changes in habitat conditions and for developing regional corridors/priorities within the Southwest.

- Develop more cost-efficient and user-friendly land management predictive models, taking into account the potential to adapt relevant models and technologies from other disciplines.

4.3 WOODLANDS (SKY ISLANDS)

Chair: Charles Van Riper, U.S. Geological Survey

Woodlands, also referred to as sky islands, represent an important ecological system in the Southwest because of the diversity of habitat and species they contain. Across the region extending from the Mojave to the Sonoran to the Chihuahuan Desert Basins, elevation changes in association with mountains significantly increase biodiversity. The isolation of the sky islands has generated patterns of endemic and locally isolated species, some of which are rare. Neotropical influence has led to many species having northern limits in the sky islands region. These may be locally rare, but most are abundant to the south. Some species have been impacted by anthropogenic factors (e.g., climate change, invasive species, habitat loss, and fragmentation) and are now rare, though previously they were more abundant. Some species, on the other hand, are temporally restricted to the sky islands in that they are stopover migrants or temporary visitors.

While the majority of the sky islands in the United States are managed by the U.S. Forest Service[8] and a significant portion are in fact located in Mexico, important ties to DoD, both direct and indirect, do exist. Conservation objectives and actions should be prioritized with regard to the causes of rarity and threats faced as well as coordinated with other land managers. Further, there is a need to anticipate and plan for large-scale disturbances that are increasingly likely. Below is the list of identified priority needs in ranked order (though the group felt they were largely equal) for recovering TER-S and keeping common species common in the sky islands:

- ***Evaluate fire as a disturbance regime relative to the sky island ecological system***. Invasive species, particularly grasses, increasingly are impacting landscapes in the Southwest. With these invasions, changes in fire regimes relative to the sky islands are occurring because of fuel continuities from lower elevations. Efforts are needed to model the transition of fuels upslope to assess potential impacts. Research also is needed to assess the seasonality of ignition in terms of its implications for related fire management approaches. Overall, a

[8] In 2004, the Rocky Mountain Research Station brought together scientists, managers, and other interested parties to identify needs and possible solutions for existing and emerging problems in the sky islands related to biogeography, ecosystem monitoring, science-based management, cultural resources/history, invasive species, hydrology and biodiversity, conservation planning, ecology, fire, conservation practice, and global climatic change. Full proceedings are available at http://www.fs.fed.us/rm/pubs/rmrs_p036.html.

landscape approach focused on controlling NIS will be necessary to effectively manage fuel loads and fire hazards to native habitat and species.

- ***Research metapopulation dynamics and dispersal potential both within and across mountain ranges***. A small local population isolated from other populations is prone to local extinction, but the species may have a chance of survival in a network of habitat patches connected by dispersal. To effectively manage endemic and locally isolated species, research is needed to assess metapopulation dynamics both within and across mountain ranges with respect to genetics, demographics (i.e., patchiness), and source/sink populations. The conservation value of sky island systems for both endemic and more mobile species, including migratory species, may be ascertained from such studies. In addition, opportunities to maintain diversity in consideration of anticipated large-scale disturbances should be explored (e.g., assisted migration or colonization).

- ***Assess response of sky island ecological system to broad-scale climate-driven change***. With the present realities of climate V/C, there is an increased probability of drought in the Southwest. Such conditions overall will lead to reductions in montane habitat and changes in plant phenology. Research is needed not only to assess specific causes and future impacts at the system level but also to identify desired ecosystem goods and services (both maintained within this system and extended across systems) such that management efforts can be targeted and adapted in anticipation of changes. In particular, opportunities to reset or assist systems in responding to climate change and variability should be investigated. With the new successional dynamics that will follow disturbance, which species should be reintroduced, favored, or eliminated? The transmission potential of pests in these circumstances is also a consideration.

- ***Investigate alterations of synchrony in phenologic and demographic processes***. Efforts to assess the causes and consequences of pulsed processes (e.g., masting, recruitment, and mortality) should target key species across the sky islands, particularly pollinators. Research is needed to determine the role of corridors, climate, debt, and key species in altering as well as sustaining processes. Climate V/C have the potential to significantly alter the synchrony of the processes.

- ***Explore the geography of rare species in sky island systems***. Patterns of species rarity in the sky islands are diverse. To manage these species effectively, basic information on their distribution, abundance, and limiting factors is needed. Inventories and surveys along ecotones should be pursued. Further, an improved understanding of the different forms of rarity is needed. Both extinction and recolonization within the system may be occurring. Efforts should be undertaken to conduct a sensitivity analysis of stressor impacts on habitats. Bioclimatic modeling also may be a useful tool to explore issues related to rare versus common space and the ability of species to maneuver through the system. Within the broader context of a landscape and ecosystem management focus, there is a need to effectively integrate critical single-species conservation efforts.

- ***Assess the impacts of changes in seasonality, particularly as they relate to the sky island system***. Global climate change has the potential to impact the growing season in the West by as much as 90 days. Species distributions are likely to shift upslope as a result. There is, however, a disconnect between impacts of changes in seasonality at varying elevations. As elevation increases, the relative significance of temperature versus precipitation in maintaining system dynamics shifts although the point at which the switch occurs is largely unstudied. How species will adapt to changes in seasonality, adjustments in phenology, predicted community associations, and the potential for lag effects are relevant research topics. Changes in seasonality also may impact the timing of ignition of fuel loads within adjacent ecological systems. An extensive fossil record exists, which could be leveraged to explore issues of seasonality.

- ***Evaluate the impacts of fragmentation and access limitations to the sky island system***. The sky islands are by their very nature isolated. Urbanization, energy exploration, recreational activities, and border issues in the surrounding area, however, are severing connectivity among sky islands for wide-ranging species and increasing long-distance dispersal rates along roadsides of both NIS and native species. Research is needed to assess the system impacts of an increased human footprint in the area, including habitat loss and fragmentation, new sources of colonists, human commensals such as house cats, and management constraints. Alternatively, management of access may buffer systems from such impacts. Efforts should be undertaken to assess impacts across DoD installations versus lands without access limitations.

4.4 INTERMITTENT STREAMS AND DRY WASHES

Chair: Andrew Hautzinger, U.S. Fish and Wildlife Service

The purpose of this session was to examine gaps in knowledge related to the intermittent streams and dry wash systems of the desert Southwest. Discussions focused on the paucity of information for these understudied systems. Knowledge of baseline conditions, physical and ecological processes, and species presence is needed. Five main themes emerged during the group's discussions—patterns, processes, ecological linkages, species-specific knowledge gaps, and decision management tools. All of the following priorities, listed in rank order from highest to lowest, nest within one of these main themes.

- ***Conduct baseline surveys***. Because of significant gaps in basic knowledge, fundamental information on current conditions is needed. This information should include species occurrence, abundance, and spatial extent at a minimum.

- ***Determine specific ecological information for critical target species***. To best manage both TER-S and keystone species within these systems, there is a need to examine habitat characteristics, ecological thresholds, life histories, and population viability. Additionally, an examination of existing species is needed to

determine if any are specially adapted to these ephemeral systems. If any are, tools will need to be developed to best manage and study these organisms, thereby facilitating management of critical species before they become imperiled.

- ***Develop tools for rapid and cost-effective management***. Because intermittent stream and dry wash systems are often transient in nature, there is a need to develop or adapt current remote monitoring tools. For example, tools such as Light Detection and Ranging (LIDAR), hyperspectral imaging, and satellite imagery could be tailored to specifically hone in on these systems. Further, more cost-effective tools are needed to determine system flow rates. This information will help personnel develop adaptive management and predictive models to help manage these systems.

- ***Improve understanding of the underlying physical and biological processes of intermittent and/or ephemeral streams***. Akin to the baseline surveys, there is a lack of information on the basic processes driving these systems. Information such as nutrient cycling, pollination, propagation, hydrologic cycle (ground and surface water cycling), the effect of climatic variability, and natural disturbance regimes need to be studied to understand the interaction between the physical and biological systems. With this information, land managers will be able to develop models to help determine the importance of these areas.

- ***Examine the underlying ecological linkages within and between hydrosystems***. Because these systems are currently understudied, little is known about how their processes are linked either within the system or between perennial portions and adjacent uplands. Core information related to groundwater and surface water exchange, hydrogeomorphic surface and subsurface characteristics, and the modes of transport for propagules, wildlife, nutrients, and sediment is needed to help link these systems across the landscape. This information will help managers to minimize impacts to the TER-S that either live in these systems or utilize them as nursery and breeding grounds.

- ***Develop an Index of Biotic Integrity (IBI)/reference condition characterization for intermittent/ephemeral streams and dry washes***. To properly determine the health of any system, a reference state based on either the best attainable condition or historic conditions is needed. As part of determining ecosystem reference conditions, there is a need to verify the best possible water quality, habitat, and species assemblage, as well as the indicator species that best describe these habitats. With this information, managers can better determine relative system health.

- ***Identify, characterize, and understand the effects of anthropogenic stressors***. Land managers need to be aware of resource-relevant challenges under all conditions. Climate variability, development, fire, and military activities can exacerbate these challenges. Therefore, a need exists to characterize the various

impacts of anthropogenic stressors on aquatic ecosystems and, once identified, to understand their myriad potential impacts.

- ***Characterize land use impacts, both positive and negative, on intermittent, ephemeral, and dry wash systems***. Little is known about the impacts of different land uses on transient aquatic ecosystems. Information is needed on seasonality, spatial and temporal distribution, and impacts of disturbances on the landscape, including in the upland systems and across the aquatic system. Further, comparative information for unimpacted sites is needed to determine the impact different land uses are having on these ecosystems.

Breakout group participants identified a number of lower priority needs for intermittent stream and dry wash systems, including development of:

- Improved restoration methods,
- A queryable database of existing information,
- An estimation of system values, and
- Quantifiable estimates for the impacts of NIS.

5.0 SESSION 2: ECOLOGICAL PROCESSES AND THEIR VARIABILITY IN SPACE AND TIME

Ecological processes and, as a consequence, associated biotic responses have variability in both space and time. Temporal variability is especially critical in the desert Southwest, in which a change in the frequency or timing of a process may present process-dependent species with unfavorable habitat conditions for periods of time to which they are not adapted. Ephemeral plants, fire-adapted species, and hydrologic regime-dependent species all respond to the natural variability inherent in ecological processes and often negatively to human alterations of such processes, including their variability. Similarly, the effects of fragmentation and NIS on ecological processes, including current impacts, projected trends, and potential mitigation need to be considered. In this session, groups divided into the following topic areas: *Fire Regimes; Climate Variability and Change; Fragmentation;* and *Hydrology and Ecology of Southwestern Intermittent Streams, Dry Washes, and Adjacent Riparian Zones*. The desired session outcome was for participants to identify information needs relevant to key ecological processes in the Southwest.

5.1 FIRE REGIMES

Chair: Matthew Brooks, U.S. Geological Survey

Fire regimes are patterns of fire over the landscape over time. Fire frequency has increased in the desert Southwest shrublands but has decreased in most other areas, including desert grasslands, woodlands, and lower elevation forest. Fire frequency and intensity is likely to increase due to climate change and the continued spread of invasive grasses. Increased fire in desert scrub is a significant concern. It is important to understand and be prepared to react to the impacts fire regime changes will have on species composition and ecological processes. Discussions resulted in the following three top priorities for addressing fire regimes:

- ***Improve knowledge of the ecological effects of fire and fire regimes***. This knowledge is a key element in achieving the ability to manage fire and its effects on TER-S habitat. Research is needed to improve understanding of the contribution of NIS to unwanted fire regimes and the biology of NIS affecting fire regimes. There is also a need to examine the influence fire has on the viability of TER-S and the effects of fire and fire regimes on species composition. Related to this is the need to understand how fire affects soil and hydrologic properties. Finally, it is important to know more about how fire affects community trajectories and ecosystem functions.

- ***Identify the best tools or approaches for creating desirable fire regimes***. To identify the best ways to create desirable fire regimes, there is a need to determine strategies for fuels and fire management from the perspectives of effectiveness and side effects. Further, it is important to know the effectiveness and side effects of post-fire recovery strategies. Knowledge of how to manage single fires will also lead to knowledge of fire regime management. Best fire regime policies must be determined for regional, state, and local levels. Appropriate prevention

strategies (e.g., managing ignitions, education, and outreach) need to be identified. Finally, there is a need for information on how to break the exotic species-fire cycle.

- ***Determine the possible future conditions of habitats in the Southwest given changing fire regimes***. To fill this knowledge gap, several issues need examination. There is a need to know how changing vegetation and climate will affect fire regimes. The influence of invasive plants and past fire management policies on future conditions should be examined. The influence climate and/or fire have on making landscapes more vulnerable to invasion by NIS should be better understood. Better knowledge of which species are most likely to invade landscapes is needed. Information is also needed to facilitate determining if pre-settlement conditions are viable or reasonable landscape targets. If they are not reasonable, there is a need to be able to determine landscape targets that are reasonable and desirable.

5.2 CLIMATE VARIABILITY AND CHANGE

Chair: Timothy Hayden, U.S. Army Corps of Engineers

Climate variability and change is having increasingly significant, yet poorly understood impacts on ecosystems throughout the Southwest. This breakout group identified eight high-priority topics to better understand ecological processes and their variability in space and time, relative to climate V/C.

- ***Develop information/tools to evaluate the relative role of climate variability and change versus other factors and cumulative effects***. The group identified two specific tools that would be important to research and develop in order to better understand climate V/C. First of all, research is needed to develop a framework/tools (e.g., database) for information sharing for the purpose of “evidence-based conservation” and adaptive management. This would allow proper feedback and adaptive management in response to human influences and landscape change. Secondly, the group identified the need to develop a decision support system model based on predictive landscape models with integration of monitoring. Similar research tools were identified in Session 1-2.

- ***Research the time-space domains of large-scale ecological variance and assess how they interact with the spatio-temporal scales at which climate varies and changes***. The group was concerned that more local and taxonomically focused research and compilation of data were required to assess species/system response to climate V/C. Such information would also be important for determining whether predicted changes in the mean climates and their variability weaken the power of a system to support diversity. For example, what is known about seasonal variability and linkages between ecology and hydrology? Such relationships may be important in predicting system response to climate V/C. Other ideas for research focused on comparing modern plant distributions and fossil records of plants to climate change and utilizing those relationships to better

predict landscape-scale changes in the Southwest as a result of predicted climate V/C.

- ***Research how to use the full range of climatic forecasting capabilities and knowledge of ecological response at the scale of months to years to improve the success rate of management approaches***. Currently, DoD and other agencies do not fully utilize the established relationships built into climatic models to formulate land management and schedule training. For example, existing models can be used to determine the likelihood of long-term regional droughts or severe weather events that may be important when formulating land management and military training plans that may only succeed under certain climatic conditions. Thus, it is important to research the effects of climate change on human usage of the landscape and to develop tools that would allow land managers and trainers to utilize this information when making short- and long-term plans. Furthermore, these models can be utilized by agencies to assist in developing mitigation or adaptive management approaches to address regional- or continental-scale climatic changes that may occur in subsequent years. It was also recognized that agencies need to better define their roles and responsibilities relative to land management for listed species in light of predicted changes in climatic conditions.

- ***Research the response of disturbance regimes (e.g., invasive species, fire risk) to climate V/C***. The interaction of multiple stressors, such as climate change coupled with NIS and other disturbance regimes (e.g., fire risk), needs to be researched. For example, climate change could significantly impact (both positively and negatively) NIS threats posed by particular species, as well as the timing and rate of invasions. To address this issue, it may be important to conduct retrospective studies to determine how climate variability impacted the rate and severity of past invasions. Furthermore, basic research is needed to better understand the impact of NIS on native plants and animals (community structure), as well as baseline inventories of NIS. With respect to fire disturbance, how will weather, climate variability, and climate change affect fire risk and behavior in the newly flammable ecosystems of the southern deserts? Research is needed to develop models to help design and test management regimes for fire prevention and suppression.

- ***Determine whether there are significant ecological thresholds that initiate system change in response to climate V/C***. Past evidence suggests that ecological systems may have “ecological thresholds” that when surpassed initiate substantial system changes (e.g., replacement of dominant species). Thus, research is needed to determine whether the consequences of climate change will be manifested as threshold ecological events. If such thresholds exist, research is needed to identify and describe the physiological thresholds and metrics for plants at different (or the most appropriate) spatial scales (species or community level). In particular, the role of temperature and precipitation regime changes in creating these threshold events at different spatial scales needs to be investigated. Such research should

also address the relationship between climate change and recruitment and mortality.

- ***Research whether climate change influences temporal variability at multiple scales (seasons, diurnal)***. The group identified the need for additional research to evaluate the relationship between climate change and temporal variability at multiple scales. Much of the climate research is focused on global- and continental-scale climatic conditions. For land managers, more emphasis is needed to assess regional-scale issues and factors that may significantly impact regional ecosystems, including seasonal/diurnal cycles.

- ***Research specific management recommendations that DoD can use on military installations and at landscape scales with partners to mitigate the effect of climate V/C***. Global climate change problems and solutions need to become regionalized and localized in order to develop meaningful management solutions and mitigation measures through partnering. To that end, research is needed to develop specific management measures and partnership efforts that DoD can implement to reduce the effect of global climate change on mission processes relative to land management and future restrictions that may be imposed indirectly as a result of growing ecological threats to already vulnerable systems.

- ***Research how to continue to deliver ecosystem services and quantify the cost/benefits to humans and natural systems (trade-offs and consequences)***. Given limited resources to address the effect of climate change at the regional level, it will be important to demonstrate how preserving these systems yields direct quantifiable benefits to humans and natural systems. Furthermore, cost/benefit analysis techniques may be important to demonstrate how such investments are cost-effective. Thus, research is needed on how to continue to deliver ecosystem services and to quantify these benefits, relative to the cost, for both humans and natural systems.

5.3 FRAGMENTATION

Chair: David Mouat, Desert Research Institute

The effects of fragmentation as a process are understood for a few individual species, but a broader understanding is needed as to whether fragmentation may cause species or groups of species to fall below critical population levels that negatively affect viability. In particular, additional study is needed to tie landscape metrics indicative of fragmentation to a biological component (e.g., core habitat, dispersal) that is meaningful for informing management decisions across multiple jurisdictions. Further, predictive capabilities of fragmentation across the landscape that take into account current and future impacts of climate, urban, and land-use change throughout the region are needed to enable assessments of ecological process continuity and future species distributions. Based on this information, best management practices (BMP) for landscape management that mitigate these impacts and take into account scale and multiple uses can be developed. Below is the list of identified priority needs in ranked order for managing fragmentation in such a way that biodiversity is maintained in the Southwest region:

- ***Translate landscape metrics into indicators that are tied to a biological component***. In other words, what does a connectivity index mean for a particular species or group of species? Research is needed first to determine how fragmentation affects core habitat/patch size for sessile species and dispersal/permeability of other species that use a patch in an ephemeral area. Landscape metrics with biological significance then can be identified. Once identified, efforts are needed to assess how they can be monitored over time and how they can be applied to different geographic regions. Without a clearer understanding of how fragmentation impacts species viability and habitat requirements as well as tools for monitoring large-scale land-use change over time, proactive management actions cannot be targeted effectively.

- ***Assess how various barriers—border, roads, fences, canals—affect landscape and habitat viability***. Following impact assessments, BMPs to mitigate effects for existing barriers as well as new barriers are needed. These BMPs should aim to ameliorate interruptions of connectivity (both in and out).

- ***Develop predictive capabilities that take into account climate, urban, and land-use change to provide analysis of future species distributions in various ecological systems***. Such models would provide an improved foundation for understanding species impacts, facilitate identifying trends and management options, and serve as an analytical tool to assist policy and decision makers across jurisdictional boundaries in making informed decisions and collaborating. To achieve these analyses, more refined regional-scale data are needed to project footprint growth (urban as well as infrastructure) and incorporate climate change.

- ***Develop BMPs specifically for landscape management***. Research is needed to assess how landscapes can best be managed to protect their ecological integrity across jurisdictions, while sustaining other missions for the land. In particular, efforts are needed to incorporate the sociopolitical aspects of fragmentation (e.g., alternative energy development) and identify mechanisms to inform decisions. The context-specific nature of BMPs and issues of scale also are essential.

- ***Transition scientific studies, data, and results to inform management practices***. Research is needed to better understand how to transition scientific knowledge in a spatially explicit (i.e., more context-specific) manner such that field implementation via informed management actions is possible. Targeted audiences include decision makers, implementers, and the public. Infusion of scientific knowledge also will help legitimize the concept of sustainability.

- ***Identify the critical fragmentation issues currently facing the Southwest region***. In addition to predicting future issues resulting from fragmentation, there is a need to assess the critical fragmentation issues currently facing the Southwest. Fragmentation should be evaluated in relation to specialized habitats or landscape features that provide broader ecosystem services (i.e., benefits). Identification of

these issues can inform prioritization of research, management, conservation, and partnership efforts focused on specific landscapes and habitats.

Other needs identified by this breakout group included:

- Explore reconciliation ecology as a potential tool to address fragmentation.
- Determine how landscape elements respond to disturbance and assess the spatial and temporal influences on recovery time given aridity of environment. From this information, it may be possible to establish thresholds for level of impact.
- Apply concept of fragmentation and associated principles as a land management tool to protect landscape and habitat values, while enhancing mission capability by avoiding a sink or problem in a specific area (i.e., use in a positive way).

5.4 HYDROLOGY AND ECOLOGY OF SOUTHWESTERN INTERMITTENT STREAMS, DRY WASHES, AND ADJACENT RIPARIAN ZONES

Chair: Andrew Hautzinger, U.S. Fish and Wildlife Service

Similar to the findings in Session 1.4, this group determined that there is a paucity of information on the processes driving intermittent streams, dry washes, and adjacent riparian zones in the Southwest. They also determined that these systems described are only a small portion of the ephemeral aquatic systems across the desert Southwest. A more complete list would include tinajas, cienegas, valley bottom flood plain, upper watershed, and spring/seeps, all systems that are dependent on the intermittent flows prevalent in the Southwest. As these systems are generally understudied, there is a significant knowledge gap. Four main themes, in order of importance to the workgroup, emerged as follows: underlying physical and biological processes within systems, human impacts to ecological processes, remote sensing and other tools to define systems, and processes that link systems. Each of the below listed priorities fall under one or more of these themes.

- ***Determine the biological, hydrological, and geomorphological processes within the systems***. Several key pieces of information are lacking to describe the processes occurring in these systems. Among them are nutrient cycling, reproductive biology, flow requirements, water quality, climatic variability, natural disturbance regimes, and riparian processes. Each of these main ideas was further fleshed out to determine its role in the system and what specific information was lacking.

- ***Determine the impact of NIS on ecological processes***. The role of NIS in these systems is not well understood. While it is widely known that NIS can often replace the niche of native species, in ephemeral systems NIS can impact both habitat and the hydrology driving these systems. Therefore, research is needed to determine how NIS affect not only the landscape but also the underlying processes driving the health and survival of these systems.

- ***Determine the keystone/indicator species***. Keystone and/or indicator species can be important metrics of the function of the underlying processes driving these systems and should be identified with the ultimate goal of better understanding the system.

- ***Determine the feasibility of using remote sensing and other tools to describe the spatial extent of these systems***. Since these systems are often in remote areas and transient in nature because of the variability in water flow, it is difficult to determine their actual existence as well as temporal and geographical extent. Currently, managers rely on rudimentary methods to describe these parameters. A more cost-effective mechanism to collect these data would involve applying remote sensing tools. Therefore, a need exists to determine the feasibility of using and/or adapting existing tools to assess the extent and nature of these areas.

- ***Determine the feasibility of using surrogate information to infer habitat availability and quality***. Related to the above priority, more effective means to quantify the available habitat and its relative health within these ephemeral systems are needed. Surrogate information—temperature, vegetation analysis, precipitation—can be used to determine not only the presence of habitat but also its rough condition. Once identified through surrogate measures, researchers then can ground truth the data to determine actual extent and health. The use of surrogate information would streamline the process of locating these habitats and provide for more cost-effective use of resources.

- ***Determine the processes that link systems***. While this overarching theme did receive some votes of importance from the group, it was not identified as a top priority. Included in this theme are processes that provide a vital connection between otherwise unrelated areas. These processes also can link systems in ways that are not readily apparent, including, but not limited to, recruitment, hydrologic cycle, climate, disturbance, sediment transport, NIS, aeolian processes, and keystone/indicator species that are shared between systems.

- ***Determine the process needs for restoration***. After basic knowledge of these systems is expanded, the extent to which restoration is needed and what processes are most important to restoration success should be examined. First and foremost, there is a need to determine the attainable endpoints for restoration and how much of an impact disrupted processes can have on achieving these endpoints. Second, a need exists to determine the feasibility of restoring these areas in the face of NIS, climate change, and the loss of hydrologic integrity. Finally, a need exists to generate public support for these restoration endeavors.

In addition to the above mentioned priorities, several other priorities were discussed within the session, each falling under one of the main themes. These priorities included determining the climatic effects on hydrology and water availability, the effects of fire on flora and fauna and water availability, and how human disturbance affects the fire cycle.

6.0 SESSION 3: MONITORING, MANAGEMENT, AND COORDINATION ACROSS BOUNDARIES

Assessing regional biodiversity requires recognition of spatial scale effects and how appropriate metrics may nest across scales. Resource managers often lack contextual information by which to evaluate their own monitoring data. In this session, groups divided into the following topic areas: *Effects of Spatial Scale*, *Regional Condition Metrics*, *Hierarchical Monitoring*, and *Partnerships and Information Sharing*. The desired outcome of this session was to identify relevant and appropriate partnership opportunities, data gaps, and management approaches.

6.1 EFFECTS OF SPATIAL SCALE

Chair: David Mouat, Desert Research Institute

Relevant elements of spatial scale in the Southwest were considered around the theme of identifying how spatial scale and hierarchical monitoring (nesting of data across scales) affects identification of the data that should be collected and how it should relate across scales. The group agreed that this discussion of scale should include both spatial and temporal scale. Organizations and jurisdictions often define the scale needed to address issues independently. Military installations need to consider the scale of their own installations but also need to look at features outside the boundaries of installations, perhaps at different scales. Managers have a specific place-space view of scale, but researchers often do not have the same perspective of scale. Science and management do not seem to operate on a mutual scale and should be better related. There is a need to select design aspects of information collection that facilitates movement across scales. Data collected on a small scale are being used to make landscape-scale decisions without the rigor to do so. Efficient mechanisms are needed to select the most appropriate scale for the issues at hand. Data collection commonality is rare and contributes to the issues of selecting the right scale for the issue. Managers and researchers need to adhere to the practice of adaptive management. The group identified needs and gaps in five categories—multi-scalar linkage, tools, scaling, spatial/temporal indicators, and agency. The results are the following five needs in priority order:

- ***Improve or develop multiscalar linkages***. Modeling approaches and experimental designs that allow analysis at various scales need to be developed. Efforts are needed to plan, analyze, and create conceptual models that provide links between scales. Sampling design and data protocols should be standardized for efficient use in multiscalar analysis. In addition, spatial/temporal scales of biophysical drivers and ecological responses must be reconciled.

- ***Develop tools that help resolve spatial scale issues***. Project design should allow feedback between scientists and managers. Research tools for multiscalar applications need to be developed (i.e., craft more sophisticated ways to make decisions about scale). Decision support tools for recognizing spatial and temporal variability are needed. Models need to have sufficient sensitivity to predict and reflect future and current landscape conditions.

- ***Improve the ability to rigorously apply collected data at various scales***. Techniques to scale from research plot to landscape scale and to validate/verify the results are needed. Standardizing, to the extent possible, spatial sampling methods in field studies will provide more certainty and efficiency in moving among scales. Improved ways to quantify uncertainties of moving among scales are needed.

- ***Improve understanding of spatial/temporal indicators***. Research is needed to identify indicators for assessing and predicting the impacts of various influences on species, habitats, ecosystems, or landscapes. The viability of the umbrella species concept[9] to cut across scales for species and habitats also must be determined.

- ***Integrate agency-scale approaches***. Agencies need to determine and implement ways to reconcile differences in the scale of their operations. Methods and processes that use site-specific information to inform larger scale challenges and issues are needed. Research partnerships for cross-boundary issues need to be promoted and supported.

6.2 REGIONAL CONDITION METRICS

Chair: Larry Voyles, Arizona Department of Game and Fish

This group identified and recommended ten priorities relative to the development and utilization of regional condition metrics. These priorities were organized into three categories—management, basic research, and measurement/monitoring. In many respects, several of these research priorities and recommendations could be integrated as part of a unified research program that seeks to develop regional condition metrics that serve various needs. The group felt that each research topic outlined below was equally important and thus they were not ranked relative to priorities. Research topics and specific elements to be addressed by such research are presented below.

6.2.1 Management Priorities

- ***Research existing regional metrics and identify areas of commonality to facilitate use of existing efforts***. The work group discussed many of the agency and collaborative efforts currently under way to develop metrics at the national- and global-scale (e.g., *Environmental Indicators of the Nation* published by the Heinz Center, National Research Council [NRC] indicator publications and research, the NEON program, the United Nation's Millennium Assessment, NPS's inventory and monitoring [I&M] programs, and the U.S. Environmental

[9] An umbrella species is defined as a species whose conservation is expected to confer protection to a large number of naturally co-occurring species. This concept has been proposed as a tool for determining the minimum size for conservation areas, selecting sites to be included in reserve networks, and setting minimum standards for the composition, structure, and processes of ecosystems. Among the species suggested as potential umbrellas, most are large mammals and birds, but invertebrates are increasingly being considered. Roberge, J-M., Angelstam P., Conservation Biology, Vol. 18, No. 1, Feb. 2004. pp. 76-85.

Protection Agency [USEPA] environmental indicators program]. It was recognized that development of regional indicators should not "re-invent the wheel," and thus research should be undertaken that evaluates existing efforts to determine commonality.

- ***When developing regional metrics, take into account their applicability to national-level metrics***. Given that U.S. policy and funding decisions are made at the national level, it is important that regional metrics are integrated with existing national-level metrics that will be used, in part, to make national-level decisions for funding, staffing, and policy/regulations. Thus, research and development of regional metrics should also take into account applicability to national-level metrics (e.g., methodology for rolling up regional results to existing national-level metrics).

- ***Develop local/installation-level metrics that feed into national- and regional-level metrics***. Individual land managers would collect metric data at the local/installation level. These metrics must serve their individual land management needs. Given funding constraints, it is unlikely that parallel monitoring efforts will be undertaken to collect needed data to feed into regional- or national-level metric compilation. Therefore, research is needed to determine how best to design a system that would allow for the integration of local/installation-level metrics into regional- and national-level metrics.

- ***Improve understanding of why specific metrics are measured***. When designing a regional metric, it is important that there be a clear rationale and purpose as to why specific metrics are being measured. To that end, research and development of regional metrics needs to demonstrate the underlying biological and systems rationale for the metrics, as well as the management and policy-level utility relative to local-, regional-, and national-level metric integration.

6.2.2 Basic Research Priorities

- ***Work with/collaborate with partners to design a regional monitoring program that is sufficiently robust to measure change within the major ecosystems***. This group, as well as other sessions (e.g., Sessions 1-2 and 2-2), identified the need to track and monitor change at the landscape level. Research is needed to identify and develop robust regional metrics and monitoring programs that will measure change within major ecosystems.

- ***Develop a set of tools and metrics for land managers to manage their component of the regional landscape***. Metrics that are developed need to not only track regional conditions but also enable land managers to address key land management issues facing their component of the regional landscape. In addition, land managers need tools that will allow them to utilize these metrics in a model that would enable them to forecast and predict landscape change. Thus, research and development is needed to build tool sets for land managers that will allow

them to assess regional landscape changes. Similar tools were recommended in other sessions (e.g., Sessions 1-2 and 2-2). It was pointed out that land managers often lack the resources and technology to adequately develop and/or apply sophisticated tools; thus, such metrics and tools need to be "practical" for the land manager to implement.

- ***Establish reference species areas at the ecoregional level for charismatic flora and fauna***. Land managers recognize the value of managing at the ecosystem and habitat-level rather than individual species. Yet, there are policies/regulations and strong public opinion that favors land management goals focused on protecting charismatic flora and fauna species. Research is needed to identify such charismatic reference species at the ecoregional level that would serve as good surrogates for the overall ecosystem in order to achieve basic ecosystem goals, while also protecting these charismatic species. The potential limitations and strengths of such an approach, as well as potential supplemental metrics, also should be studied and quantified to ensure that multiple objectives are met.

- ***Develop economic indicator metrics of ecological services***. There was considerable discussion about the fact that there are numerous metrics in the financial sector that are tracked and monitored regularly at multiple levels by an array of agencies, NGOs, and private sector businesses. The driving force behind their continued use and monitoring is the financial benefits gained by such efforts relative to the cost. It is recognized that the landscape provides similar economic benefit, yet its value is difficult to quantify, let alone the change in economic yields relative to investing in the landscape (e.g., invasive species control, habitat restoration, or other prescriptive measures employed by the local land manager). As a first step, basic research is needed to develop economic indicator metrics to quantify and track ecological services derived from the landscape.

- ***Research and develop methods for quantifying the value of DoD lands relative to species diversity and other ecological services (e.g., carbon sequestration)***. ***Research and develop methods for creating a "currency of conservation" for DoD lands and diversity***. Building on the previous research objective, a more specific research question was identified relative to the contribution of DoD lands to the overall economic value of the regional landscape. If DoD could quantify its contribution to the overall value of the landscape, it may be useful when devising regional and partnering strategies, as well as potentially developing trading credits relative to habitat restoration and carbon sequestration. In the long term, such efforts may serve to protect or enhance/expand training missions on military lands. Thus, research is needed to quantify the potential value of DoD lands and management measures, policies, and conservation projects outlined in installation Integrated Natural Resource Management Plans (INRMP).

6.2.3 Measurement Priorities

- ***Develop regional metrics***. Participants developed a list of key metrics that would be important to include as a component of regional monitoring research programs. Refining this list relative to ongoing local/installation-, regional-, national-, and global-scale indicator efforts will be important to ensure proper synthesis and to achieve multiple objectives at these levels. These metrics are:
    - Water budget
    - Phenophases of species
    - Biodiversity of native species
    - Exotic species contribution (impacts to biodiversity)
    - Measuring ecoservices
    - Fire frequency, intensity, and spatial distribution by vegetation type
    - Species movement (including man), habitat loss, fragmentation
    - Soil erosion/disturbance
    - Pathogens and vectors
    - Landscape change/land-use vector with existing DoD imagery
    - Numbers of TER-S

6.3 HIERARCHICAL MONITORING

Chair: Mark Sogge, U.S. Geological Survey

Hierarchical monitoring (nesting of data across scales) offers great potential for leveraging limited resources as well as capturing the landscape/system level when assessing the status of the overall biodiversity of a region. Essentially, as spatial coverage decreases, the intensity of monitoring and process knowledge increases. A detailed understanding of I&M activities at multiple levels of resolution is necessary to realize the benefits of hierarchical monitoring.

Within the Southwest region, a number of ongoing initiatives seek to coordinate monitoring across administrative boundaries—NEON, USGS Southwest Regional Gap Analysis, NPS I&M networks (e.g., Sonoran Institute), and the USA-National Phenology Network. DoD’s current level of involvement varies by initiative. Challenges to realizing hierarchical monitoring through these initiatives are numerous, ranging from different and changing missions, goals, objectives, and organizational structures driving effort; long-term funding; and staffing limitations to varied or nonexistent metadata, protocols, and classification schemes. Further, information management that enables not only landscape assessments but also data analysis and reporting generally is lacking.

Below is the list of identified priority needs in ranked order for establishing a framework for and realizing the benefits of hierarchical monitoring in the Southwest region:

- ***Support regional symposium on TER-S monitoring and develop proceedings from event to disseminate results***. TER-S monitoring efforts are ongoing by multiple agencies throughout the region; however, coordination generally is lacking to support hierarchical monitoring across the landscape. A regional

symposium would provide an initial opportunity to assess the level of effort being devoted to monitoring by agency or locale as well as targets and protocols. Such a status assessment then could serve as a basis for follow-on workshops that explore specific opportunities for coordination throughout the region. Documentation of the results in the form of proceedings was recommended.

- ***Catalog ongoing inventory and monitoring activities on and around DoD installations***. Beyond a regional symposium to encourage information exchange, efforts are needed specifically to catalog ongoing I&M activities on and around DoD installations. Opportunities to leverage resources and data are numerous but not without detailed knowledge of current and planned activities. Hierarchical monitoring by definition depends on an awareness of I&M activities at multiple levels of resolution. Evaluating ongoing I&M activities and data in terms of their efficacy, rigor, and quality control measures would be a natural follow-on step. Further, are the monitoring data currently being collected relevant to management?

- ***Create interagency thematic expert teams to assist with protocol development, mapping, and data collection in support of hierarchical monitoring***. Use of enterprise teams by the BLM and the USFS to tackle issues such as wildland fire potential and riparian ecosystem health could be used as a potential model. The availability of additional resources to staff and fund activities of these teams will be critical to their success given current demands on existing staff.

- ***Establish a national-level proponent for natural resource monitoring***. Without clear delineations of the mission, responsibility, authority, and budget to conduct coordinated I&M activities, hierarchical monitoring is likely to remain an elusive goal. Efforts are needed to communicate the benefits of coordinated I&M activities as well as the consequences of not doing so to policy and decision makers. Partnerships across sectors will strengthen the message as it rises to higher levels. Further, there may be a role for "Government Accountability Office (GAO)"-like reports and evaluations to garner support in establishing a national-level proponent and dedicated resources for natural resource monitoring.

- ***Design, test, and evaluate monitoring protocols and train practitioners in their use and implementation***. In particular, training workshops on the use of TER-S monitoring protocols are needed. Such efforts will facilitate higher quality I&M data for informing management decisions and actions.

Other needs identified by this breakout group included:

- Conduct workshops with regional land managers to identify shared goals (sense of mission) in support of initiating and realizing hierarchical monitoring.
- Develop communication tools (newsletters, listservs, web sites, etc.) to share information on ongoing and planned I&M activities.

- Develop repositories to store inventory and monitoring data, facilitate quality assurance/quality control (QA/QC), enable analysis at various scales, and develop products useful for management decisions. Existing repositories to explore leveraging include the National Biological Information Infrastructure (NBII), Colorado State University, NatureServe, and NPS.
- Establish partnerships with NGOs and others through working groups to facilitate and transcend boundaries with regard to monitoring (joint ventures as a model).
- Develop tools and approaches to compare current inventory and monitoring data with historical data given changing associations, protocols, and technologies.
- To improve coordination of inventory and monitoring activities, reevaluate boundaries of Cooperative Ecosystem Studies Units (CESU) as they do not always align well with ecological regions.
- Within the DoD TES Document Repository, for ease of use, provide links to existing I&M networks as well as data repositories.

6.4 PARTNERSHIPS AND INFORMATION SHARING

Chair: Valerie Morrill, U.S. Army Yuma Proving Ground

Discussions focused on the state of partnership opportunities across the desert Southwest. The group first shared experiences in established partnerships and listed "what we know" about the current state of those partnerships. Lessons learned about how the partnerships work, how they recruit members, and how funding is elicited for their continued success were emphasized. The group then discussed what the gaps in information sharing are across the region. The main thread connecting many of the gaps was a need to coordinate across borders and take into consideration magnitudes of scale when creating partnerships. The top priorities are listed below:

- ***Coordinate monitoring efforts through partnerships on long-term and regional scales***. Given the current funding climate, there is a lack of support for long-term monitoring efforts. Long-term data is a vital aspect of the management and conservation of fragile habitats across the desert Southwest. In addition, there is a lack of coordination of monitoring efforts that span jurisdictional boundaries. Data collection needs to be consistent across both jurisdictional and ecosystem boundaries to ensure the best possible generation of results for the most users.

- ***Develop a standard protocol/management system for data collection and storage within an ecoregion***. While an abundance of valuable data is being collected in the Southwest, much of it is obscure, inaccessible, or in a format that confounds its use by many people. There is a need to standardize data collection and storage to not only minimize duplication of efforts but also ensure that the data is easily transferable between researchers and managers. In addition, by standardizing protocols, teams can address relational, regulatory, and access issues from a central point, minimizing potential problems at the data collection phase.

- ***Establish a standard, cost-effective way to move and secure resources between federal, state, and non-profit agencies***. While the group acknowledged the success of the CESU program, there remains a lack of support to easily move resources between entities. There is a need to provide consistent funding and associated mechanisms for partnerships that do not have members as part of the CESU program.

- ***Increase public support for conservation***. In recent years, there has been renewed public support for conservation efforts; however, the education and support to sustain this level of enthusiasm is lacking. More resources are needed to help educate the public on the costs and benefits of conserving natural resources.

- ***Coordinate partnerships across borders***. While the normal border issues of federal, state, and private lands are at play in the Southwest, additional borders with Native American lands and Mexico add another layer of coordination not found in other areas. More communication and outreach needs to be done to bring these neighbors on board with existing partnerships or to create new partnerships that address the special issues that may arise when managing natural resources across these jurisdictions.

7.0 SPECIAL SESSION: LEGACY PROGRAM PROJECT IDEAS

Chair: Lew Gorman, U.S. Fish and Wildlife Service

Although not formally scheduled, several workshop participants felt it was important to specifically identify projects of potential interest to DoD Conservation and the Legacy Resource Management Program. These recommendations focus on management and/or policy areas. The following list captures priorities identified in this breakout group.

- ***Assess regional metrics to identify areas of commonalities***. Identify common metrics used in the Southwest to maximize use of ongoing and planned efforts among multiple agencies. This effort could lead to unification of indicators of Southwest ecosystem health.

- ***Develop a regional compendium of landscape-scale issues and management actions to address them***. Such a regional management handbook would describe the overarching landscape-scale issues based on current scientific information.

- ***Develop criteria for selecting priority streams and washes for conservation monitoring and assessment***. This regional, multi-agency tool would be based on current knowledge of what makes certain streams and washes important.

- ***Develop a bibliography and searchable database on the ecological and hydrological functions of ephemeral/intermittent stream and dry wash ecosystems***. This would facilitate recognition of important functions and thereby improve conservation of significant ecosystems.

- ***Predict future invasives and their impacts on DoD and adjacent lands***. Using current knowledge, a report that predicts invasive species establishment and possible impacts would enable advance preparation and development of management techniques.

- ***Identify undesirable vegetation impacts on water budget***. A report on the impacts of vegetation changes (e.g., establishment of invasives and altered fire regimes) is needed by managers in the Southwest to understand water availability and its influence on habitats.

- ***Implement a "living with wildlife" outreach program working with DoD, conservation partners, and surrounding communities***. The focus would be on military families living on installations and activities for interacting with the habitats they live in.

- ***Deploy DoD-wide acoustic monitoring to document and detect the seasonal timing of tree-bat migration***. This effort anticipates using the technology already developed by SERDP, ESTCP, and other military Service research to improve knowledge of tree-bat migration.

- ***Evaluate caves and mines on DoD facilities for at-risk bat habitat***. A report of the significant hibernacula and roosts on DoD lands would enhance the ability to protect bat habitat, help prevent the need for listing of at-risk bat species under the Endangered Species Act, and improve information for selecting caves for military training.

- ***Establish reference species areas at the ecoregional level for charismatic flora and fauna***. A list of areas in the Southwest that typify significant habitats would help managers protect and manage them.

- ***Establish a monetary value for DoD ecosystem services provided by military installations in the Southwest***. Such an effort would improve communication among a broader audience and provide a new outreach tool for DoD to portray the positive influences of military installations.

- ***Update and expand the known list of species at risk (rare species) to show current distribution in the Southwest***. The existing list, completed in 2002 through a past Legacy project, relied on data that is now at least six years old and is now dated, creating gaps and inaccuracies.

- ***Improve collaboration by enhancing understanding of federal agency land use missions, policies, monitoring, research, and conservation in the desert Southwest***. Outreach may help integrate conservation efforts and accomplishments.

- ***Develop a regional desert Southwest fire management plan***. A multi-agency plan could integrate policies and practices across the region.

- ***Conduct a pilot effort on a military installation in the Southwest to assess the value of ecotourism***. This is an opportunity to determine if military installations and communities can benefit financially or otherwise allowing visitors who are interested in viewing and learning about nature.

- ***Evaluate availability of seed sources for DoD desert scrub restoration***. A list of seed sources to use in desert scrub restoration (e.g., after a fire) is needed.

- ***Evaluate the potential for using native species to manage cantonment/industrial areas, enhancing species at risk populations***. A best management practices report or handbook for landscaping in military cantonment areas may be a logical product of this effort.

- ***Develop cross-border cooperative conservation partnerships***. Identify the best opportunities and develop conservation partnerships with organizations in Mexico. For example, broader regional coordination will help in conserving at-risk bat populations throughout their range.

- ***Determine how management activities can influence and minimize the threat and effects of fire in sky islands***. This need is closely linked to invasive species management efforts.

- ***Develop and test spatial models that integrate management of invasive species, threatened and endangered species, and fire risk/hazard potential***. Such models will facilitate a regional approach that incorporates partnerships with multiple land managers.

- ***Work with various partners to develop and test bottomland monitoring protocols for Southwestern rivers***. Implementation of these protocols will fill key data gaps.

- ***Determine locations and connections of pollinators***. Baseline information is needed in addition to predicted trends in consideration of climate change.

- ***Develop information tools on fire management for senior leaders***. Fire is both a land management tool and a threat to native ecosystems if uncontrolled. Outreach to senior leaders will help facilitate appropriate use of fire as well as measures to prevent it.

8.0 PRIORITY OUTCOMES

After the conclusion of the formal workshop, a small group consisting of breakout group chairs, white paper authors, and the workshop sponsors engaged in a half-day meeting to review, clarify, and refine the recommendations and priorities expressed during the workshop. Following are the prioritized outcomes of this session.

8.1 ECOLOGICAL ROLE OF FIRE AND CAUSES AND ECOLOGICAL EFFECTS OF ALTERED FIRE REGIMES IN THE SOUTHWEST

Background

The historical role of fire varied widely among ecological zones in the Southwest. Grasslands, shrublands, woodlands, forests, and associated riparian systems provided divergent fuels supporting fire regimes with widely ranging frequency, intensity, severity, spatial complexity, and seasonality. Land uses, plant invasions, and human population growth have led to the alteration of fuel conditions and fire regimes, but the effects have been as varied among vegetation zones as are their potential remedies.

Perennial grasslands largely existed because of frequent surface fire that prevented encroachment by woody species. Fuels removal by livestock and fire suppression by humans has dramatically reduced the frequency of fire, allowing woody species to supplant perennial grasses in many areas. Subsequent changes in soil properties and the invasion of non-native perennial grass species confound attempts to restore native grasslands. Prescribed burning has been implemented to reverse these trends, but the seasonal timing of these fires appears to benefit non-native versus native species. Effective management strategies are needed to replace woody with herbaceous species, promote the dominance of native species, rebuild soils, and restore desirable fire regimes of frequent, low intensity, surface fires in native perennial grasslands.

Shrublands comprised mostly of creosotebush (*Larrea tridentata*) at lower elevations, interior chaparral species at middle elevations, and sagebrush (*Artemisia tridentata*) at higher elevations historically dominated much of southwestern North America. Fire was largely absent at lower elevations, due to shrubs being widely spaced with little vegetation between them to carry fire. Invasions by non-native grasses during the past century have filled these interspaces and allowed flames to propagate into large fires. Stand-replacing crown fires historically occurred at middle and higher elevations as woody shrubs slowly accumulated over many decades to levels that could carry fire. Currently conditions have changed relatively little at middle and higher elevations compared to lower elevations. Management strategies are specifically needed to manage fine non-native fuels and reduce the size and frequency of fire in lower elevation shrublands.

Woodlands dominated by oak, pinyon, and/or juniper species ranged from closed canopy stands with little understory vegetation to oak savannas adjacent to grassland zones. Accordingly, fire regimes ranged from high-intensity, stand-replacing, crown fires to low to moderate intensity, mixed-severity, surface to passive crown fires (i.e., fire spread is primarily on the surface, but some of the trees are burning). In some areas livestock grazing and fire suppression have allowed these woodlands to encroach upon grasslands and middle elevation shrublands. The

densification of many of these stands is now to the point where only crown fires are possible. Management strategies are needed to thin woodland species from encroached areas and restore natural fuelbed conditions and fire regimes.

Low elevation forests dominated by ponderosa pine (*Pinus ponderosa*) were historically described as park-like due to the open nature of their understories. Open understories were maintained by frequent, low to moderate intensity, surface fires that spread beneath the forest canopy. For more than a century, surface fuel removal by livestock grazing and fire suppression have led to understories described as dog-hair thickets choked with dense woody fuels that can carry flames into the canopy and result in undesirable high-intensity crown fires. Management strategies are needed to modify these understory fuels, reintroduce frequent surface fire, and restore native vegetation conditions in these forests.

High elevation forests dominated by Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa)*, and corkbark fir (*Abies lasiocarpa var. arizonica*) occur in relatively small stands at the highest elevations in the Southwest. Short growing seasons and slow accumulations of woody fuels resulted in infrequent fires occurring every few hundred years, but when these fires did occur they were high intensity and severity, stand-replacing fires. The century of livestock grazing and fire suppression that altered fire regimes at lower elevations likely had little effect at these highest elevation forests where fire return intervals are on the order of centuries. Accordingly, relatively little concern exists that past land uses have affected this ecological zone, though regional fire ecologists have great concern that future climate warming could produce conditions under which these forests cannot persist.

Significance

One of the most powerful driving forces in the evolution of species is the disturbance regime. The presence and the absence of a particular type of disturbance, plus the characteristics of that disturbance (e.g., frequency, intensity, spatial complexity, etc.) affect both the suitability of habitat for a species and the forces of natural selection that can directionally change the characteristics of a species over time. Rapid changes in disturbance regimes can render habitat unsuitable for extant species, and if these changes occur too swiftly, they do not allow enough evolutionary time for species to adapt to the new conditions. In addition, during previous times species ranges shifted across broad regions, basically following their preferred habitat as it changed over time. Today the Southwest is becoming increasingly fragmented with many barriers to range shifts by species. Finally, species are managed within discrete management units, such as military installations, which remain geographically static. Fire regimes are defined by their intensity and temporal and spatial patterns of occurrence. Shifting fire regimes pose threats to species wherever they occur, though it is unclear which species may be most susceptible to the changes.

As described in the previous section, the most significant changes in fire regimes have occurred in the grassland, low elevation shrubland, woodland, and low elevation forest regions of southwestern North America. Grasslands and low elevation shrublands comprise the vast majority of military installations in the Southwest, woodlands comprise a smaller proportion, and low elevation forests are the smallest constituent. Plant invasions have had their greatest effects

on fire regimes at lower elevations, especially in shrubland ecosystems. Future shifts in climate could affect the relative abundances of these vegetation types and the dominance of non-native plants, which can affect future fire regimes. These changes are expected initially to take effect at the ecotones between the major vegetation types.

Recommendations

Appropriate fire regime objectives need to be identified for each land management unit in the Southwest. Fire regime targets need to be based on both historical (i.e., pre-settlement) conditions and current conditions (e.g., climate shifts, plant invasions), and they need to account for both spatial and temporal variability (i.e., they cannot be static targets). New information is needed to inform this process, specifically to determine the appropriate balance between historical targets and other criteria that reflect current and potential future conditions. Information is also needed to evaluate the effects of plant invasions and future climate change scenarios on current fire management practices.

Specific research is needed to:

- Evaluate the effects of single fires versus fire regimes on vegetation, TER-S, and biodiversity in general.
- Develop assessment tools to rank the negative effects that shifting fire regimes are having on TER-S and to triage sites for restoration treatments and basic fire ecology research.
- Develop prioritization tools that land managers can use to develop appropriate fire management goals and objectives, particularly to determine if historical conditions (e.g., pre-settlement) or some other set of conditions (e.g., that will enhance TER-S habitat) are most appropriate.
- Develop assessment tools that managers can use to evaluate the potential for non-native species to negatively affect fire regimes so these species can be prioritized for early detection, control, and ideally eradication.
- Develop management strategies to effectively manage fuels (both native and non-native) to achieve desired fire management goals.
- Develop Standard Operating Procedures (SOP) for various stages of fire management (e.g., fire planning, fuels management, fire suppression, and postfire management) that will minimize the potential for non-native species to establish and/or increase in dominance.
- Evaluate the effects of future climate change scenarios on vegetation and fire regimes and their combined impact on TER-S.
- Evaluate the effects of future climate change scenarios on current fire management practices (i.e., are current practices likely to remain relevant in the face of future climate changes?).

8.2 IMPACTS AND MANAGEMENT OF NON-NATIVE INVASIVE SPECIES IN THE SOUTHWEST

Background

Non-native invasive plants and animals are recognized as significant threats to economic and ecological values throughout the Southwest as well as much of the United States. All habitats—aquatic, riparian and terrestrial—are at risk. Non-native invasive species (NIS) threaten southwestern land and waters, whether managed by private, state, or federal entities, including DoD. By definition, NIS result in harm to the natural environment. This may be from, for example, influencing changes in ecosystem processes (e.g., changes in fire regime) or a large-scale displacement of native species by the often aggressive colonizing behavior characteristic of many NIS. Although such traits have long been present in the environment, recent human alteration of natural systems has tilted the 'survival of the fittest' in NIS' favor. The human impact may be visible such as with the conversion of natural landscapes to development or less apparent such as with exacerbating climate change. In Southwest arid lands, a disastrous consequence of non-native plant invasions is the introduction of wildfire into ecosystems that are not fire-adapted. For example, within decades, sparsely vegetated desert scrub areas of creosotebush and bursage (*Ambrosia* spp.) have been transformed into grasslands of buffelgrass (*Pennisetum ciliare*), brome (*Bromus* spp.), or Mediterranean grass (*Schismus* spp.) capable of carrying fire.

In addition, aquatic and riparian habitats suffer from a number of invasive plants such as giant salvinia (*Salvinia molesta)* and salt cedar (*Tamarix* spp.), as well as invasive fauna such as bullfrog (*Rana catesbiana*) and crayfish (*Procambarus clarkii)* and others. TER-S are especially vulnerable to harm from NIS. In a recent study, subject matter experts and land managers in the Southwest ranked NIS as the second greatest threat—next to habitat loss—to the ecological integrity of the Sonoran Desert (Marshall, 2000). Alarm was so prevalent during the Southwest Region TER-S Workshop about the impact of NIS on TER-S, nearly every breakout session identified NIS as a priority concern.

Significance

Non-native invasive species are known to significantly impact ecological system structure, composition, and function and thereby also adversely impact associated TER-S. In the Southwest, extensive tracts of deserts and chaparral are transforming into forb-lands and Old World grasslands. Riparian cottonwood and willow stands succumb to salt cedar (*Tamarix* spp.*)*, Russian olive (*Elaeagnus angustifolia*), and Siberian elm (*Ulmus pumila*). Aquatic invasive animals such as crayfish and bullfrog decimate native fauna populations. In Arizona, the Governor's Invasive Species Advisory Council recognized "Whether we know it or not invasive species affect each of us, and their threats and impacts are a growing concern in Arizona. They are already having a negative effect on the state's economy, natural environment, and human and animal health. Their presence has caused, among many harmful effects, the loss of wildlife habitat, decreased agricultural productivity, degraded watersheds, and increased fire danger, as well as the introduction of human and agricultural diseases" (http://www.governor.state.az.us/AIS). Across the Southwest, biodiversity diminishes and vital ecosystem services are lost in the presence of NIS. Such services may include soil stabilization

and pollination for rare plants. Impacts to socioeconomic services can be dire as NIS compete for precious water resources in the Southwest, damage crops, and depreciate recreational values. For DoD, although it isn't considered a significant source of new introductions of NIS in comparison to other activities such as development, agriculture, and transportation, its land and water uses can contribute to the NIS problem. Especially critical are surface disturbance activities often associated with military operations and the potential for military equipment to serve as vectors for NIS. Additionally, DoD-unique missions such as weapons firing and explosions may serve as ignition sources, indirectly exacerbating related NIS problems such as wildfire. Also of concern is the likelihood that DoD installations in the Southwest are threatened by direct and indirect impacts to mission execution from NIS, especially as related to TER-S and their stewardship responsibilities.

Recommendations

As in many regions, the distribution of NIS in the Southwest is widespread, and their control is often deemed too costly and too difficult to be feasible. In reality, the opportunity to fully restore many southwestern ecosystems to their pre-invasion state is long past, and such efforts would be at best impracticable and likely impossible. Given that, the approach to thwart the ongoing NIS assault should be to prioritize efforts that provide the most benefit or protect the most valuable resources. Even with this tactical approach, this will require a comprehensive, multiyear tiered program of research and management crosscutting multiple disciplines and partners. To make a difference, there will need to be a change in public perception including a commitment to address the problem of NIS at a scale befitting it as a major disaster or as the epidemic that it is. At a minimum, research should focus on improved understanding of baseline information about NIS, the environments at risk, and potential management responses.

Specific research topics should focus on the following:

NIS Factors:

- ***Investigate the current patterns of invasion in the Southwest and how NIS are most likely to invade in the future***. Relate NIS to other ecosystem processes in the Southwest–such as fire, hydrology, pollination–and to the potential of NIS to exacerbate risks, particularly to TER-S.

- ***Develop models to understand potential scenarios for new NIS introductions as well as potential distributions of current NIS infestation***. A geographic assessment and synthesis of NIS distribution with respect to other resource data such as TER-S distribution could provide a scaled approach to analyze cumulative effects. Such spatial population and habitat modeling techniques should be considered to achieve a landscape perspective and to reduce costs.

- ***Develop a basic understanding of NIS characteristics and life histories to determine the factors that portend invasiveness and factors that may respond to management prescriptions***. Identify which NIS significantly alter ecological processes, how such processes are at risk, and how NIS impact can be mitigated.

Furthermore, determine which NIS directly impact native plants and animals, especially TER-S, as well as how such species are impacted, and how to alleviate NIS effects.

Environmental Factors:

- ***Investigate basic ecological system characteristics, especially in regard to ecological processes, that either promote vulnerability or increase resiliency to invasion by NIS***. This is particularly true for disturbed habitats–understanding how local, landscape, or regional anthropogenic disturbance patterns contribute to these NIS occurrence patterns compared to relatively undisturbed sites. Similarly, it is important to know which ecological processes are amenable to management intervention and at what spatial scale.

- ***Assess TER-S and other resource risks to determine which ecological systems in the Southwest should be the priority for research on and management of NIS***, especially with regard to those that occur on military installations.

- ***Forecast the implications of climate change in the Southwest, including changes in climate variability, on the distribution and ecological responses of NIS as well as the responses of native species to NIS***. Moreover, assess the role of climate V/C on past invasions and how it can inform predictions of future invasions. Investigate how progressive warming will interact with precipitation variability to determine the timing and rate of invasions. Design models that predict how climate change might interact synergistically with altered fire and hydrologic regimes to affect the invasion process.

Management Factors:

- ***Develop potential management strategies to monitor, eliminate, minimize, or otherwise mitigate and restore habitats from the impacts of invasion***. Evaluate NIS prevention measures, early warning monitoring strategies, and rapid response procedures for containment on DoD facilities and neighboring lands, and recommend how can they be improved or expanded.

- ***Develop tools/models to evaluate current NIS monitoring protocols, forecast the spread of NIS, and model future NIS scenarios in response to land use change and climate variation***. Include technologies to enhance early warning detection and monitoring.

- ***Analyze NIS prevention and control technologies, and develop improvements─including rapid response protocols for incipient infestations***. Identify how management actions can minimize damage to sensitive resources and rehabilitate or restore previously disturbed properties. Determine what kinds of disturbances result in new NIS infestations, and develop rapid response measures to prevent their occurrence.

- ***Assess the prospects for using resistant (i.e., more competitive) individuals of native species as a means to mitigate the impacts of and control NIS*.**

8.3 MANAGEMENT NEEDS FOR OVERCOMING THE IMPACTS OF ALTERED FIRE REGIMES

Background

Altered fire regimes in the Southwest pose management challenges for the maintenance and recovery of TER-S and their associated habitats. In this region, altered fire regimes affect large areas of desert scrub communities, semi-desert grasslands, and montane islands (woodlands and forests) that are often surrounded by the desert scrub and grassland communities. Within each of these communities are embedded rare aquatic habitats, limited occurrences of unique soil types, and other edaphic or geographic features that support TER-S and must be considered with regard to fire and restoration management. To overcome these challenges, management strategies and tools are needed for restoring the fire regime or alternative management practices that are appropriate to the ecological system under consideration, as well as an understanding of desired and achievable future conditions associated with that fire regime.

Significance

Overcoming the impacts of altered fire regimes can be particularly challenging in the arid Southwest. For example, desert scrub communities (mixed shrubs, succulents, and grasses) require the absence of fire, yet are increasingly faced with more frequent and geographically extensive fire occurrence, sometimes exacerbated by DoD mission-critical activities such as live-fire exercises and training with pyrotechnics. In contrast, many woodland, forest, and grassland communities require some fire for maintenance but have experienced excessive fire suppression. Reintroduction of managed fire regimes can be complicated by other local and national restrictions, such as air quality requirements that are important for environmental health, but which can limit the tools available to fire managers. Furthermore, DoD facilities are embedded within matrices of natural, semi-natural, and human-dominated systems, which can potentially increase liabilities for neighbors on either side of the fence. If fuel and fire management are not coordinated across boundaries, they can cause friction among management agencies and reduce the viability of TER-S populations and the systems they inhabit. Cross-boundary coordination of resource management is a necessity for the proper and successful management of TER-S and the systems they inhabit. In spite of these fire management challenges, well-coordinated partnerships that consider TER-S recovery and maintenance potentially reduce the burden felt by particular members, especially when partners can share the responsibility for fostering a healthy and dynamic habitat matrix across the landscape. Furthermore, the natural ecological systems that are restored and maintained provide an effective and sustainable training and testing environment.

Recommendations

Partnerships with neighboring entities are essential to the success of cross-boundary management and are intended for inclusion in all recommendations. A three-tiered approach to the

development of fire management strategies to overcome the impacts of altered fire regimes is recommended.

- ***Baseline information acquisition, modeling, and synthesis phase***. These topics perform and enable a comprehensive regional management plan for DoD facilities and their surrounding areas and partners, thus increasing value and reducing overall management costs.
  - Determine fire behavior patterns and fire effects within and across vegetation types (e.g., fuels continuity, ignition sources, fuel loads, fire effects on soil and hydrologic properties, and fire effects on community trajectories, across trophic levels, and on ecosystem function).
  - Determine TER-S habitat requirements (on and surrounding DoD installations) by conducting geographic assessments and synthesis of TER-S and their habitats.
  - Incorporate connectivity and future disturbance scenarios (including fire) for TER-S by conducting a geographic assessment and synthesis of habitat condition with respect to fire issues (e.g., fuels continuity, ignition sources, burn histories, burn plans).
  - Use spatial population and habitat modeling techniques to link TER-S, their habitats, and fire issues with other issues to reduce costs.
- ***Based on the habitat and fire assessments for installations and their surrounding areas, define management strategies and tools that are needed to create desirable fire regimes***. Fire management plans should include consideration of historic conditions, desirable and achievable goals with respect to DoD mission including TER-S and habitat conservation, prioritization of management actions based on TER-S needs and concerns, and action plans for remediation where damage has already occurred or will potentially occur as a result of management actions. The following considerations are critical to understanding the role of fire and its management in efforts to restore and maintain ecosystem function across the DoD installations of the Southwest:
  - Provide decision support tools/models needed for fire prevention, suppression, and prescribed burn planning and implementation while maintaining proper ecosystem function.
  - Establish the appropriate fire prevention strategies (e.g., managing ignition sources, alternatives to fire, education/outreach) by identifying appropriate fuel suppression/reduction tools and pre-treatments in relation to TER-S and consistent with DoD mission.
  - Identify optimal regional, state, and local policies for achieving desirable fire regimes across jurisdictional boundaries and within appropriate ecological boundaries.

- ***Given the existence of altered fire regimes and prospects for continued change, develop viable plans for effectiveness monitoring***. Where appropriate, link this topic to other important topics such as ecosystem recovery, NIS, and climate change.
    - Establish a framework to determine if appropriate or desired responses have been achieved.
    - Investigate how the presence of NIS and past fire management policies affect what is achievable as future conditions.
    - Develop databases and modeling techniques that can be used to evaluate how existing vegetation structure and composition may interact with future climate variability and fire in ways that affect TER-S and the DoD mission.

8.4 IMPACTS OF CLIMATE VARIABILITY AND CHANGE IN THE SOUTHWEST

Arid and semi-arid landscapes in the Southwest, host to burgeoning human populations attracted to the Sun Belt, may be particularly sensitive to projected climatic changes associated with the buildup of greenhouse gases (GHG). The prospects of climate change for the region include increased warming and drying, intensification of droughts in the region, and possibly increased variability of precipitation. Warmer winters and longer growing seasons may relax cold constraints on the upper and northern limits of native and a growing list of introduced species, most of which originate from Mediterranean, tropical, and subtropical regions of the world. Longer growing seasons and hotter summers will decrease soil moisture, reduce evaporative cooling, and thus increase further, latent heating of the land surface. The challenges for land and resource managers are both immediate and long-term, raise questions about the understanding about the interactions of climate and ecosystems, and point to key research and management needs. The impact to TER-S in the region is expected to be particularly significant.

Background

The latest climate predictions for the Southwest in the 21st century come from intermodel comparisons for the recent Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (IPCC, 2007). These intercomparisons focused on the A1B scenario, which assumes a future world of rapid economic growth, global population growth that peaks at 9 billion by 2050 and declines subsequently, and advancements in energy technology and policy. This conservative scenario would essentially double atmospheric carbon dioxide concentrations to 700 parts per million by 2100.

The averaged output of 18 general circulation models (GCM) for the Southwest indicates approximately 3°C warming by the end of the 21st century, with slightly more warming in summer than winter and most of the warming accomplished between 2030 and 2060. Simulations from the 18 GCMs generally agree that the subtropics (i.e., the Southwest) will become drier while the high latitudes become wetter throughout the 21st century (Seager et al., 2007). This is because increased global temperatures increase atmospheric humidity, which in turn causes increased moisture divergence and northward expansion of the poleward edge of the Hadley Cell and mid-latitude westerlies. High pressure aloft over the Southwest is a persistent

feature across several general circulation models. For the Southwest, Seager et al. (2007) suggest that by 2100 the mean climate for the Southwest could resemble average conditions during the 1950s drought.

To overcome the low spatial resolution of GCMs, Diffenbaugh et al. (2005) used a dynamic regional climate model to explore the sensitivity of U.S. climate under A2, which is a worst-case scenario. The A2 scenario can be characterized by more international conflict and less cooperation, few technological advances, high population growth (15 billion by 2100), low income per capita, high energy and carbon intensity, no efforts to curb GHG emissions, and an estimated carbon dioxide level of 840 parts per million by 2100. The regional climate model indicates that the Southwest could experience extreme hot events five times more frequent than the reference period (1961-1985) by 2071-2095 (Diffenbaugh et al., 2005). In the Southwest, the cause of the more frequent and longer heat waves in the regional climate model appears to be driven by negative evapotranspiration anomalies, related decreases in latent cooling, and amplification of direct radiative heating of the surface layer. In the Diffenbaugh et al. (2005) regional climate model, geopotential heights and anticyclonic flow become enhanced at 500 hPa over the southwestern United States and northern Mexico. Questions remain about the direction of interactions between these large-scale changes and finer-scale changes in surface moisture balance; however, high pressure aloft is a feature of GCMs that do not fully capture finer-scale changes in surface-moisture balance and their feedbacks to the atmosphere. Diffenbaugh et al. (2005) also found enhancement of extreme precipitation over coastal areas dominated by convective precipitation, such as in the Sierra Madre-Gulf of California, due to increased sea surface temperatures. This could potentially increase summer precipitation in the United States-Mexico borderlands, but transport of this moisture north of the borderlands will depend on how far north the subtropical monsoon ridge migrates over Nevada and Idaho.

Compelling evidence suggests that the climate has already begun to change across the western United States. Abrupt warming across the West beginning in the 1980s brought on a marked increase in springtime temperatures, an earlier onset of spring by 8 to 10 days, a rise in the elevation at which it rains rather than snows, a decrease in snowpack, earlier snowmelt timing, a shift to an earlier pulse of snowmelt-fed discharge, and an increase in the frequency of large fires (Cayan et al., 2001; Stewart et al., 2005; Mote et al., 2004; Knowles et al., 2006; Westerling et al., 2006). A recent detection and attribution study focused on these recent changes by downscaling output from two GCMs that reproduce important features of western U.S. climate to a regional climate model and then a regional hydrological model. Only the simulations that considered historical increases in GHG can explain the observed trends and spatial fingerprint of warmer winter-spring minimum temperatures, decreased snow water equivalent normalized for precipitation, and timing of snowmelt-related streamflow in the western United States. (Barnett et al., 2008).

The present warming may already be driving lower annual streamflows in the Upper Colorado River Basin, and it could progressively lower reservoir levels in Lake Powell and Lake Mead (Hoerling and Eisheid, 2007; McCabe and Wolock, 2007; Barnett and Pierce, 2008). Hotter and longer growing seasons also may have exacerbated the effects of the 1999-2004 drought, producing intense bark beetle outbreaks and broadscale dieoffs of pinyon pine, ponderosa pine, and other southwestern trees (Breshears et al., 2005). The warming could explain other forest

dieoffs that are now occurring simultaneously from British Columbia to the sky islands of Arizona and New Mexico. Under a warming climate, where the length of the growing season is now different than it was when the dying vegetation was established, such large-scale dieoffs produce opportunities for novel succession and invasions by both native and non-native species.

In the deserts, warm season temperatures rose gradually over the past 3 or 4 decades; whereas, winter and spring minimum temperatures rose sharply, again in the mid-1980s. For the Sonoran Desert, Weiss and Overpeck (2005) show lengthening of the freeze-free season and increased minimum temperatures per winter year. They suggest contraction of the overall boundary of the Sonoran Desert in the southeast and expansion northward, eastward, and upward in elevation. Bowers (2007) used phenological models based on triggers and heat sums to predict the annual date of spring bloom for shrubs from the northern Sonoran Desert. The models showed advances of 20-40 days in flowering time from 1894 to 2004, which were verified using herbarium specimens. This earlier bloom eventually could have substantial impacts on plant and animal communities in the Sonoran Desert, especially on migratory hummingbirds and population dynamics of shrubs. The abrupt warming beginning in the 1980s also may partly explain rapid spread of red brome (*Bromus rubens*), buffelgrass, and other introduced tropical and Mediterranean grasses and herbs that increase fire occurrence in desert vegetation and will continue to spread northward and upward with progressive warming.

Significance

DoD manages approximately 8.8 million acres of land across the Southwest region. Approximately 110 TER-S have important habitat on DoD lands. More of these species occur per acre than on any other federal lands. A number of key questions are of note about how these species and their habitat will respond to climate change in the 21st century:

- What are the time-space domains of large-scale ecological variance and how do they interact with the spatio-temporal scales at which climate varies and changes? Ecological variance here includes both annual and episodic phenological and demographic phenomena. Specifically:
  - What geographically or taxonomically focused studies or studies on specific species/ecological system responses to climate V/C should be pursued to improve understanding of these interactions?
  - Will predicted changes in the mean climates and their variance adversely impact the role of environmental variability in supporting biodiversity and in individual species' adaptations to that variability?
  - How will synchrony in phenologic and demographic processes be altered across different biomes? For example, what will be the consequences to pulsed processes such as masting, recruitment, and mortality?
  - What will be the impact on the synchrony between pollinators and their host plant species? How will pollination management be impacted in terms of maintaining pollination corridors and addressing the existing pollination debt?

- Hydrologists have now declared that with an uncertain and changing climate, the conventional assumption of climatic and hydrologic stationarity (i.e., constant variance over time) in water planning is now dead (Milly et al., 2008). How will directional changes in climate, land use, invasive species, and altered fire and hydrologic regimes modify or even nullify key assumptions by land managers, principally the goal of maintaining ecosystems within the estimated historic range of natural variability? What information, tools, and models are needed to maintain biodiversity, ecosystem function, and ecological goods and services under this new, nonstationary paradigm?

- How can the full range of climatic forecasting capabilities and knowledge of ecological response at the scale of months to years be used to improve the success of management approaches? Given improved forecasting, it is possible to:

  - predict how land use will shift with climate change and what effects this may have on southwestern landscapes and natural resources?
  - better evaluate management approaches to mitigate impacts or enable adaptation to climate change?
  - project the interactions between climate change and land-use change to provide predictive analyses of future species distributions to better understand the impacts of these projections, identify trends and management options, and develop analytical decision support tools to assist managers and policy/decision makers?
  - use short- and long-term climatic forecasting to identify points of intervention and windows of opportunities for management action? For example, wet winters and springs associated with El Niño events can be anticipated 6 to 9 months in advance. Can El Niño–Southern Oscillation (ENSO) forecasting be used to plan and implement management actions that have a greater chance of success under wet than dry conditions?

- What, when, and where are there ecological thresholds capable of abrupt and irreversible ecosystem transformation? Specifically:

  - What are some of the physiological/community structure and function thresholds and metrics for measuring such thresholds for plant species/communities and at what spatial scale should these be addressed?
  - What is the relationship between climate change and recruitment or mortality?
  - What is the role of temperature and precipitation regime changes in creating threshold events at different spatial scales?
  - Will the consequences of climate change always be manifested as threshold events? In which circumstances can abrupt versus gradual ecosystem responses to climate change be expected?

- How do climate variability and change affect species and ecosystems that occur on military installations in the Southwest?
  - Which ecosystems/biomes are most at risk?
  - Which species—including keystone, TER-S, and non-native species—will contract or expand their ranges radically with climate change?

Recommendations

- ***Climate models***. Right now, climate modeling studies focused on the Southwest are happening *ad hoc* and with limited interaction with land and natural resource managers in the region. An immediate need is to develop a sustainable, interagency framework for updating assessments of climate change impacts on southwestern landscapes and ecosystems using the latest available GCM results for different emission scenarios. Sorely needed are:
  - An inventory and evaluation of GCMs and nested, dynamical, and statistical downscaling approaches (Regional Climate Models or RCNs) to identify ones that best represent key features of southwestern climate, including precipitation seasonality and variability.
  - Development of ensemble runs for A1B and A2 emissions scenarios downscaled for the Southwest and northwestern Mexico at 50-km or better resolution and computed at 20-year intervals within the 21st century. These outputs will help set management targets for DoD and other federal agencies.
- ***Species distribution models***. Collaboration is needed among agencies and existing programs to develop and improve clearinghouses for geo-referenced distributional data for plants and animals and to compare bioclimatic models that can be used to explore potential range shifts in the Southwest. A plethora of statistical (niche-based), bioclimatic envelope models are available, each with individual strengths and weaknesses, and they all rely on point-occurrence data for species distributions. Urgent needs are to:
  - Compare and evaluate the performance of the different statistical models for predicting changes in native or non-native plant and animal species in the Southwest.
  - Establish digital libraries of species distributional data at the appropriate geospatial resolution for the Southwest [notable examples for the Southwest include U.S. Geological Survey Gap data and the Plant Atlas of the Sonoran Desert (Turner et al., 1995)].
  - Establish digital libraries of historical datasets of monthly and daily climate data that can be used to populate the bioclimatic models and that can be easily updated to the year of analysis.

- Begin to develop and test the first generation of mechanistic (process-based) distribution models for southwestern species (see PHENOFIT; Morin and Chuine, 2005).

- ***Monitoring***. Surprisingly little ecological monitoring is happening at the appropriate spatial scales across the Southwest to capture ecological responses to climate change. Routine phenological observations are being made at only a few sites. Such important processes as mortality and recruitment are not monitored at enough sites across the same hydroclimatic area to discriminate idiosyncratic behavior at particular sites from shared responses to climatic V/C across the region. Some mortality events, like the pinyon and ponderosa pine dieoffs in 2002-2003, are obvious and have been documented to some degree. For most species, however, little knowledge has been accumulated about "background" mortality/regeneration rates, what qualifies as unusually high mortality/regeneration, and current mortality/regeneration levels across vegetation types. Current needs include:

  - Establishing an appropriate set of indicator species and protocols for monitoring phenological and demographic responses to climate V/C across DoD lands.
  - Designing and implementing an acceptable level of monitoring across DoD lands.
  - Developing interagency agreements to implement the same monitoring in other federal lands; an obvious collaboration would be with the NPS I&M Program.

- ***Southwestern case study on ecological footprint of warmer winters and longer and hotter growing seasons since the mid-1980s***. Clear evidence indicates that at warm, desert elevations winter and spring minimum temperatures have warmed by nearly 1°C, average summer temperatures have also increased by 1°C, and spring onset has advanced by 8 to 10 days starting around the mid-1980s. Modeling studies now attribute these temperature changes mostly to the buildup in GHG. The case study should focus on and document the ecological responses to these greenhouse-induced temperature changes of the last two decades in the Southwest.

8.5 IMPACTS OF FRAGMENTATION AND HABITAT REDUCTION IN THE SOUTHWEST

Background

The expansion of urban land use in the Southwest has led to a widespread reduction in the size of patches of habitat. It has also led to their isolation. Patch-size reduction is thought to have a high and negative correlation with species occurrence. The effects of isolation are thought to also have a negative correlation, but one that varies considerably. As such, habitat reduction and concomitant fragmentation poses a significant management concern. Barriers between patches,

or dividers of the landscape, may be as permanent, substantial, and impermeable as an urban subdivision or as "slight" and transitory as a 4X4 jeep trail. Each type of fragmentation may have differential effects on carbon sequestration, photosynthesis, soil chemistry, surface and groundwater hydrology, and so on, which, in turn, may change the distribution and function of biological communities in the landscape. For example, inappropriate road construction that impedes the flow of water may alter the hydrologic regime of an area such that community structure, composition, and function are impacted.

Significance

Understanding how a landscape is functioning is of major importance in determining the status of habitat and its concomitant biodiversity. When the functioning of landscapes over large areas is compromised by externalities such as human development, the sustainability of those landscapes becomes questionable. An evaluation of the landscape ecology of a region must consider the hypothesis that there are spatial patterns in the landscape that will conserve the majority of natural processes. The landscape patterns vary tremendously in size as a function of habitat requirements and of the system itself (i.e., independent from the species that inhabit them). Recent research in the field of landscape ecology suggests that the spatial pattern of the landscape is integrally related to natural processes. An understanding of the vulnerability/resilience of landscapes to stress might help land managers develop strategies to ameliorate or mitigate those stresses. As such, the results of the stressed landscape, fragmentation and reduced habitat, are critical indicators of the functioning of the landscape. Resource management across landscapes must recognize that boundaries are a part of the process and that habitat may transcend jurisdictional boundaries. Management strategies must therefore take into account the political geographies than can occur within and across landscapes.

Recommendations

Because fragmentation and habitat reduction often result from differences in land use and management among different ownerships and jurisdictions, avoiding the negative effects requires the development of partnerships among landowners, land management agencies, and other political entities and organizations that are able to cooperate and manage lands from an integrated, landscape perspective. This approach allows managers to address problems at appropriate scales for meeting the needs of sensitive species in the context of ecosystem function during times of rapid climatic and ecological change. Key gaps in scientific understanding include the following issues, broken down into specific questions:

- ***Develop rigorous approaches for recognizing emerging trends in habitat fragmentation and identifying their causes***. In the Southwest, steep ecological gradients and high interannual variation in climate result in naturally heterogeneous landscapes with diverse habitats and patch configurations. In this environment, fragmentation is often not as obvious as in the forested habitats of the Eastern Seaboard and Midwest, where classical fragmentation studies have been conducted. For example, sky islands are isolated mountaintop alpine and subalpine habitats interspersed across the Southwest's large expanses—'seas'— of desert and grassland. One research need for the Southwest is basic: better

understanding of anthropogenic drivers of fragmentation and tools to assess their effects on sensitive species, many of which are adapted to naturally heterogeneous conditions. For these species, the effects of fragmentation may be subtle and difficult to quantify.

  - What are effective, unambiguous, readily interpretable, and easily monitored indicators of fragmentation in the arid Southwest?
  - How should fragmentation be assessed in naturally heterogeneous landscapes, such as the Sonoran Desert, with its steep elevation and precipitation gradients?
  - What are the relative effects of habitat loss, habitat degradation, and fragmentation on the viability of TER-S?
  - How are the impacts of fragmentation expressed spatially and temporally in habitats with high interannual variation in key ecological conditions and resources?

- ***Quantify the effects of habitat fragmentation***. In times of rapid ecological change, it can be difficult to separate the effects of habitat fragmentation from other effects, including changing microclimates and general degradation of habitat quality. Isolating fragmentation and understanding its effects can be a major scientific challenge.

  - Which southwestern habitats are most limited in area, and which landscapes are most vulnerable to anthropogenic fragmentation?
  - Which sensitive species and habitats are currently at risk, and what role does fragmentation play in their endangerment?
  - How can managers determine if management strategies are having their intended impact?
  - What are appropriate tools for determining if fragmentation effects have been appropriately mitigated or the threat of future fragmentation has been lessened?

- ***Cope with fragmentation where the process is unavoidable***. While it may seem defeatist, in some cases fragmentation of native habitats has been entrained by land use change and trends can be irreversible. In such cases, minimizing the effects of fragmentation and mitigating them, where possible, may be important strategies for protecting and recovering sensitive species.

  - How can landscapes undergoing fragmentation be managed to protect their biological diversity and ecological integrity?
  - What are appropriate monitoring strategies for assessing trends in fragmentation and habitat reduction?

  - Can landscapes be managed to minimize the effects of fragmentation, while accommodating multiple land uses?
  - How can connectivity be maintained among the southwestern sky islands in the face of development and fragmentation of habitats at lower elevations?

- ***Develop a predictive capacity for anticipating the effects of fragmentation and designing appropriate avoidance and mitigation strategies***. Fragmentation affects multiple patches of different habitat types, making management and conservation planning challenges complex. In such cases, considering the landscape-level effects requires a spatially explicit approach that projects known relationships across dynamic landscapes. Designing an appropriate response to fragmentation induced by climate change, for example, requires an understanding of likely responses in habitat quality, as well as an ability to predict how these changes will affect patch size, edge effects, and the degree of isolation among resulting patches of suitable habitat. These challenges demand a new generation of decision-support tools that are both more sophisticated and user friendly, such that they can be applied routinely by decision makers and managers.

  - Is it possible to predict how landscapes might change in the face of climate and land use change?
  - How might various climate change scenarios affect the rate of habitat fragmentation and its effects on TER-S?
  - What patch sizes, shapes, and configurations are optimal for TER-S recovery as an objective of ecological restoration?
  - What decision support tools/models are needed to inform landscape restoration, while maintaining landscape ecological function?

Many of these questions, wholly or in part, are already the subject of considerable research. A consolidated approach to identifying research priorities and setting common management goals will minimize "reinvention of the wheel" and maximize efficiency, to the benefit of landscapes facing increasing threat from habitat fragmentation, especially those resulting from human land use and climate change.

8.6 HYDROLOGY AND ECOLOGY OF SOUTHWESTERN INTERMITTENT STREAMS, DRY WASHES, AND ADJACENT RIPARIAN ZONES

Background

According to the National Hydrography Dataset, approximately 81% of all streams in the six southwestern states—Arizona, New Mexico, Utah, Nevada, Colorado, and California—are intermittent or ephemeral (USGS, 2006). Given the coarse scale of most data sources used to delineate streams across large regions in the United States, the actual density of intermittent and ephemeral streams is likely much higher for the Southwest. These dryland streams play a significant role in supporting the ecological diversity of this region by concentrating limited and highly variable moisture. Various studies have shown relative diversity and abundance of

species to be highest along these corridors in comparison to adjacent uplands (Del Rosario and Resh, 2000; England and Laudenslayer, 1995; Johnson and Haight, 1985; Jones, 1988; Kepner, 1981; Kirkpatrick et al., 2007; Rosen and Lowe, 1996; Whiles and Goldowitz, 2005). Functionally, ephemeral (dry washes) and intermittent streams transport and retain water, nutrients, sediments, and organic matter episodically in their networks and associated floodplains, support the establishment and maintenance of riparian vegetation, and provide ecologic and hydrologic connectivity to uplands and to downstream perennial watercourses. Vegetative communities along ephemeral and intermittent streams provide structural elements of food, cover, nesting and breeding habitat, and movement/migration corridors for wildlife. Functional services of these communities include moderating soil and air temperatures, stabilizing channel banks and interfluves, seed banking and trapping of silt and fine sediments favorable to the establishment of diverse floral and faunal species, and dissipating stream energy that aids in flood control.

Human population pressure, land use activity, jurisdictional boundaries, and associated land agency missions of the Southwest have introduced relatively new perturbations into these stream systems to which they have not historically been adapted. These complexities have led to the recognition that a systems approach to effective management of TER-S and other species requires careful consideration and understanding of these influences across the entire landscape.

Significance

DoD manages approximately 8.8 million acres of land across the Southwest region. Approximately 110 TER-S have important habitat on DoD lands. More of these species occur per acre than on any other federal lands.

Because of the abundance of intermittent and ephemeral watercourses that traverse these regions, and their value to many floral and faunal species, there is particular need to understand:

- How the specific hydrogeomorphic characteristics of ephemeral and intermittent streams vary throughout the Southwest.
- How the associated vegetative communities that develop within and adjacent to these streams respond to seasonal and longer term (decadal-scale) hydrologic fluxes, and what the resultant structural features are.
- Which faunal species inhabit these communities and how.
- How biological diversity within these communities may be dynamically linked to these hydro-ecologic conditions.

To date, intermittent and ephemeral stream types are often generalized by the aforementioned structural and functional properties that distinguish them from *perennial* watercourses across the Southwest. However, hydrogeomorphic features and the vegetative communities differ between intermittent and ephemeral streams. The extent to which these characteristic differences affect the composition, density, diversity, and distribution of faunal species that inhabit them is not known. Additionally, present scientific understanding of the role of these systems in supporting and linking upland and perennial stream ecosystems remains largely conceptual in scope. Differences in ephemeral and intermittent stream morphology and the associated vegetative

communities that develop within and adjacent to them likely affect the diversity and relative abundance of faunal species that inhabit them, as well as how and when they do.

Recommendations

Regional estimates of intermittent and ephemeral streams in the Southwest derived from coarse-scale maps and other remotely sensed data (e.g., National Hydrography Dataset) are not effective at capturing the true spatial extent of intermittent and ephemeral streams and cannot distinguish specific geomorphological and vegetative features associated with these stream types. To understand the role of these systems in supporting biodiversity (including TER-S) and to better assist DoD and other agency land managers in managing them for the maintenance or recovery of biological diversity, research needs have been outlined below. These are followed by an associated management need for decision support tools. The research needs also include a suggested framework within which many of the questions about intermittent and ephemeral streams elicited at the Southwest Region TER-S Workshop might be addressed. The description of needed management tools includes one example set of decision support tools that has been previously developed within a DoD framework.

Priority Research Needs

- ***Delineate hydro-geomorphic and vegetative diversity of dryland streams across the Southwest region***. A suggested effort might begin by identifying experimental watershed study areas across the Southwest region—as delineated for the purpose of the workshop—where high-resolution remotely sensed data (submeter) exist that allow for the delineation of ephemeral and intermittent streams and their associated vegetative and landscape features. Hyperspectral, DEM, and LIDAR imagery would be especially useful for this purpose. Ground truthing of remotely sensed data would be necessary. Vegetative plot data that exist on DoD installations and other public lands and generalized regional vegetation class data would be initial sources to draw from. Including the delineation of uplands in this effort would enable the study of stream network linkages to upland communities in the study areas. Identifying any hydrologic and biological records that exist within the region would also be beneficial in determining priority research areas. Data used by World Wildlife Fund (Ricketts et al., 1999), The Nature Conservancy (Marshall et al., 2006), or by the USGS Southwest Regional Gap Analysis Program (Prior-Magee et al., 2007) to identify priority conservation areas that fall within this specific region of the Southwest might be additional sources to draw from in selecting focus areas for study. The extent to which available high-resolution data that delineates ephemeral and intermittent streams in the Southwest is coincident with priority conservation areas identified by these organizational initiatives is not known.

- ***Distinguish different intermittent and ephemeral stream 'types' by their geomorphic and vegetative characteristics.*** This should fall out of the above effort.

- ***Quantify the hydrologic regime of these stream types***. There are existing hydrologic datasets for some DoD installations in the Southwest (e.g., Yuma Proving Ground, Fort Huachuca, and possibly others), and additional data exist for some dryland streams on non-DoD lands (e.g., USDA Walnut Gulch Experimental Watershed, http://www.tucson.ars.ag.gov). Should the idea of designating experimental watershed study areas be explored, selected sites across the region would ideally also house existing hydrologic datasets—particularly precipitation and flow data—given the time investment required to obtain adequate records of this kind for these systems. Other useful metadata might include soil moisture, soil temperature, and surface heat flux (bare ground and beneath canopy), meteorological data, plant water use data (e.g., sapflow, water potential), ground water table and vadose zone hydrologic data, and isotopic signatures of water inputs and storages. In the absence of existing hydrologic and meteorological data at selected sites of interest to DoD, regional climate and flow data can be used to design an instrumentation protocol for selected sites that most effectively captures the semi-arid to hyper-arid climatic gradient that exists across the region. Quantifying the space/time fluxes of water at selected sites across this region would provide the physical data necessary to elucidate how, where, and when biodiversity is associated with this limited resource.

- ***Investigate linkages of biological occurrence and stream hydrogeomorphology and associated vegetative features***. As mentioned previously, various studies suggest that faunal and floral diversity is higher along dry or intermittent washes relative to uplands, but much work remains to identify a broader range of species across different ephemeral and intermittent stream types. This effort might begin by inventorying faunal and floral species associated with each stream type and determining seasonal or episodic occurrences of these species—or specific features thereof—that might be linked with hydrologic conditions (e.g., inventorying transient vegetation following a flow event—grasses and forbs that are otherwise not present on the landscape and the faunal species that associate with them over short temporal scales—or in the case of perennial vegetation, monitoring the eco-physiological response to seasonal water availability, tracking seed and leaf production, or inflorescence, and quantifying faunal species that depend on these seasonal resources). From these data, keystone species might eventually be identified that can be used in part to ascertain the overall health of the system. The existing body of scientific knowledge as well as management priorities should be considered *a priori* in identifying both floral and faunal species of focus for the study. This information and any tools available for research and management design should be cataloged to increase their usefulness in guiding the research and management application.

- ***Investigate linkages in patterns and processes between perennial systems and ephemeral/intermittent systems***. A large body of research and data for perennial stream systems exists that could potentially be used to inform ephemeral/intermittent investigations. For example, new research indicates that dry washes downstream from spatially intermittent streams contain large and

diverse soil seed banks that include a mixture of species (Stromberg, unpublished data). Although this seems counter-intuitive, many seemingly perennial reaches of a stream are, in fact, separated by ephemeral or intermittent segments of flow as a result of natural differences in geology along the river. This variation of flow is common enough in the Southwest that hydrologists use the terms *interrupted* or *spatially intermittent* to describe the spatial segmentation of a single river into reaches that are ephemeral, intermittent, or perennial in nature. An effort to study the stream gradient framework from dry to wet reaches could be a follow-on to the first recommendation (Stromberg has done some recent work in this area). Water quality, sedimentation, and seasonal flow data on perennial rivers in the Southwest also could be used to frame research questions focused on the ephemeral and intermittent streams that feed them. Faunal records from perennial streams could be used similarly to identify species likely to be utilizing adjacent dry washes or intermittent watercourses.

- ***Identify key threats to ephemeral and intermittent stream systems, and develop predictive models on the impacts to processes important to these systems***. Urbanization, water diversion and pumping, recreational activity, invasive species, and climate change are some of the many threats faced by all stream systems, but especially to those in water-limited regions where recovery occurs over long time scales. Other influences that directly alter the hydrogeomorphic character of ephemeral and intermittent streams include road construction and chacos (impoundments emplaced in channels to capture runoff for livestock use) placed across channel flow pathways. The extent to which these influences alter the ecology of these streams is not currently known. Field and modeling efforts are required to develop a better understanding of these influences on dryland streams. Existing models need review for their application to dryland systems (there are several physically based models that could be explored), and new models may need to be developed. A premium should be placed on developing modeling techniques that would facilitate extrapolating information from existing models, which are often associated with the wetter portions of a catchment, to provide predictive capabilities for the more data-limited drier areas of a basin. This capability to extrapolate numerical modeling knowledge from the more defined perennial systems to the less known ephemeral and intermittent systems would provide important insights into what key threats are faced across an entire catchment and allow a prioritization of resource allocation.

Priority Management Needs

- ***Identify specific tools that are currently available or need refinement and develop new tools for managing for biodiversity (including TER-S) on DoD lands***.

    - *Data acquisition and synthesis tools*. Various types of remotely sensed data and field-based biological and physical monitoring data are available to accomplish many of the research tasks within the Southwest region of interest

to DoD. Several multi-agency conservation efforts have resulted in the development or synthesis of existing datasets across broader ecoregions in the Southwest toward similar ends. Considerable effort may be required to translate research findings derived from these data into tools that DoD installations can use to effectively manage for TER-S and overall biodiversity while maintaining respective military missions. Example datasets include but are by no means limited to:

- Coarse-scale spatial data that might be useful for providing ecological context for the region, identifying relevant landscape features, or elucidating areas within the Southwest region where conservation sites have already been identified through broader-scale ecoregional assessments:

    - Ecoregion-Based Conservation in the Chihuahuan Desert: A Biological Assessment. Dinerstein et al., 2000. http://worldwildlife.org/wildplaces/cd/pubs/bioassess.pdf.

    - Terrestrial Ecoregions of North America: A Conservation Assessment. Ricketts et al., 1999. http://worldwildlife.org/science/ecoregions/delineation.cfm.

    - Mojave Desert Ecosystem Program. http://www.mojavedata.gov/dataindex.php.

    - Southwest Regional Gap Analysis Program. Prior-Magee et al., 2007. http://fws-nmcfwru.nmsu.edu/swregap.

    - Ecoregion-Based Conservation Assessments of the Southwestern United States and Northwestern Mexico: A Geodatabase for Six Ecoregions. http://www.azconservation.org.

    - National Land Cover Database (NLCD). http://www.mrlc.gov/mrlc2k_nlcd.asp.

    - Multi-Resolution Land Characteristics Consortium (MRLC). http://www.mrlc.gov/mrlc2k_desc.asp.

  Development of the MRLC and NLCD datasets is discussed in Homer et al., 2004.

- Finer resolution DoD and non-DoD remotely sensed and field datasets: installation-archived vegetation plot data, hyperspectral, LIDAR, DEM imagery; local habitat distribution modeling efforts, including those designed to improve the Southwest Regional Gap Analysis (Boykin et al., in progress). Others likely exist, and above sources listed under course-

scale data might also archive finer resolution data relevant to investigations of biodiversity and ephemeral and intermittent streams in the region of interest.

- ***Dynamic Decision Support Tools.*** Applied dynamic decision support tools are needed that can address multiple management scenarios and predict alternative ecological outcomes across space/time domains. One effort toward this end has been developed by the Redlands Institute (http://www.redlands.edu/redlandsinstitute.xml) whose focus is on integrating emerging technologies for assessing and visualizing the dynamic, ecological interactions of natural environments and engineered systems and developing creative responses to emerging challenges that lie at the intersection of science, policy, and management. This group has worked with Camp Pendleton, the USFWS, and other agencies in the Southwest to develop these kinds of ecosystem management tools.

- ***Hydrologic Modeling Tools.*** Robust hydrologic modeling tools also are needed to support scenario development. An example that has been used extensively in the Southwest for scenario development is the AGWA model (http://www.tucson.ars.ag.gov/agwa) that parameterizes and runs two runoff and erosion models, KINEROS2 and SWAT.

8.7 UNDERSTANDING PATTERNS OF SPECIES/POPULATION DISTRIBUTIONS AND RARITY TO SUPPORT MANAGEMENT

Background

Broad environmental gradients in space and time—generated by highly variable precipitation regimes and complex topography—characterize the southwestern United States. Such variation influences habitats and so must also influence species populations.

In addition, dynamic patterns of growing human land use throughout the region may impair the functioning of ecosystems and certainly do create habitat reductions and fragmentation of populations. For migratory species, some habitat reductions may occur remotely leading to cryptic influences on population sizes.

More subtle, but perhaps just as important, are the biotic interactions that result from the Southwest region's high diversities of native species. These provide prey for predators and danger for their prey. And they include mutualistic relationships in which species depend on other species for their continued success. Finally, they include competitive relationships among species, relationships that have the power to restrict both population size and geographical distribution. Some of these biotic interactions may involve non-native species that become invasives.

The net result of all these influences is a large set of populations in various states of abundance, distribution, and geometry. Some species may keep fairly close to their averages. Others may fluctuate naturally (but appreciably), either regularly or irregularly. And such fluctuations may

not occur in the population sizes themselves but in reproductive rates. For example, saguaro (*Carnegiea gigantean*), the emblem of the Sonoran Desert, caused consternation early in the 20th century because it seemed to have stopped recruiting new generations. But decades of research determined that saguaro reproduction occurs episodically on a multi-decadal scale.

In addition, some species may be abundant and widespread; whereas, closely related congeners—with apparently similar physiological requirements—are restricted to a scarce and specific habitat type. Mapping habitats and overlaying species ranges on them may give a misleading picture of the fundamental niches and potential success of species with narrow geographical distributions. A picture generated by the overlay technique may be especially misleading with respect to a species' capacity to make use of novel anthropogenic environments. Moreover, today's abundant species may be tomorrow's conservation basket case—as we have seen time and again in the United States and elsewhere [e.g., American burying beetle (*Nicrophorus americanus*), American chestnut (*Castanea dentata*), passenger pigeon (*Ectopistes migratorius*), Carolina parakeet (*Conuropsis carolinensis*), and the eelgrass limpet (*Lottia alveola*)].

If a species has several populations, not all are likely to be equally sustainable. Some must be source populations (i.e., those capable of replacing themselves into the foreseeable future), but some may be sink populations (i.e., those that continue to exist only because they are regularly replenished by dispersers from the source populations). Sink populations may be very large, even larger than the largest source population.

What do such general principles imply for a resource manager? With respect to species conservation, the manager has several charges. In the shortest time frame, s/he must avert disaster for species already listed or considered at-risk. S/he would like also to engage in practices that in the not-too-distant future will either remove such species from the threat of imminent extinction or avoid placing them at risk in the first place. With a view to the long term, s/he must try to prevent today's common species from becoming tomorrow's at-risk species—thus preventing further concerns for the maintenance of efficient military training and testing operations.

In carrying out their responsibilities, managers need to know what has led the species they manage to have the population characteristics they currently possess. Has habitat important to species' persistence been lost? Has an ecosystem on which species depend grown dysfunctional? Have they lost access to a nutrient on which they depend? Are they naturally or recently scarce (or abundant)? How well do they use anthropogenic environments? Are the species populations for which the manager is responsible source populations, or do they depend on dispersal from beyond an installation's boundary? Are some species being drawn to anthropogenic habitats by inappropriate environmental signals ('trapped')? If so, can they adapt over a small enough number of generations so that those habitats become newly available to support the species? Any information that helps the manager understand the processes that have led to a set of species having their current pattern and status should help the manager plan appropriately for efficient use of time and other resources and maximum use of facilities for military training and testing.

Significance

In many cases, not having access to fundamental information about the causes of population patterns has forced managers to adopt a shortcut:

- Map vegetation and habitat types.
- Overlay population sizes on it.
- Search for correlations.
- Protect and expand the vegetation types that seem to be correlated to the highest abundances of a species at risk.

Thus, given the diverse and complex set of causes mentioned above along with the necessary simplicity of management tactics in the absence of information regarding those causes, it should be no surprise that managers, even of the highest dedication and commitment, often have some difficulty in succeeding. If the understanding of population patterns can be improved, managers will get new tools that are likely to improve their success rates with listed and at-risk species and better help them to prevent today's common species from joining those lists.

Recommendations

- ***Identify the abiotic and biotic determinants of range and range limits for both rare and common species, especially those that occur on military installations***.

  - For rare species in particular, what is the reason for their rarity? Does rarity take different forms in different species? Will these forms require different management approaches? Are some cases of rarity persistent and natural? Are some the consequence of populations being sink populations on military installations? Are some the result of changes brought about by human uses, both those in installations and those beyond—even far beyond—the fences? Are some the consequence of global climate change? Do multi-decadal alterations in temperature and precipitation influence that rarity? Do changes to interaction regimes resulting from human-use or abiotic changes affect rarity?

  - How will the patterns of rarity, source-sink dynamics, and metapopulation dynamics be affected by continued increases in anthropogenic land use and climate change across the Southwest? Is it possible to identify additional species—or groups of species—that will become adversely impacted beyond those of concern today?

  - As species change from 'safe' to 'at-risk' status, will those changes be manifested as threshold events or nearly linear responses to change in the variables that control their status? Will change from 'safe' to 'at-risk' status follow the same quantitative pathway as change from 'at-risk' to 'safe', or is one direction likely to occur much more rapidly?

- ***Deal with temporal complexity***. Perhaps no region is more obviously temporally complex than the Southwest. The successful manager will assess the role of such complexity in the species and species assemblages of the region. This requires attention to the following two problems, at least:

    - Monitoring pulsed processes (masting, recruitment, mortality, migration, seasonal torpor).

    - Determining which species depend on temporally available habitats such as those produced by fire and flood. What are the best tools or approaches for creating desirable fire and flood regimes?

- ***Manage for a changing reality***. Landscapes, ecosystems, and the species that inhabit them ebb and flow temporally and spatially. This can be especially important when new invasive species become established or when habitat needs to be converted for military uses. The manager who can anticipate such changes will produce management plans that have the firmest basis. The following research is needed to further that goal:

    - Determine the role of invasive species on native plants and animals and the landscapes they inhabit. Predict and anticipate future invasive species, either specifically or by type. Evaluate whether any practical management strategy can be used to combat unwanted effects of invasives.

    - Determine how to increase desirable species populations on DoD cantonment areas and suitable ranges to keep common species common and whether such an effort serves as an effective management strategy. Cantonment areas can function as laboratories for the applicability of this approach to nonmilitary urban and suburban communities throughout the Southwest.

- ***Work with neighbors and jurisdictions beyond the fences to spread the responsibility of good management***. The condition and fate of a species within and beyond a military fence is a package. Thus there is no clear separation between the research/management needs within a manager's installation and those of other installations as well as non-military neighbors. Managers need to develop partnerships that address these needs:

    - For species with complex metapopulation structures whose isolates probably have high rates of demic extinction (such as those living in sky island mountain ranges), investigate the possibility of counterbalancing those negative rates with assisted migration/colonization.

    - Develop conceptual models that show how installations and their surroundings are linked ecologically.

- Undertake management actions to assure the key ecosystem service of pollination. Examples include keeping track of existing pollinator corridors and establishing new ones where necessary and possible.

- ***Add to the tool kit***. New tools for management will expand the possibilities for success. Some of these tools will be conceptual and others organizational. The following priorities are suggested:

    - Investigate whether species have to be managed individually or whether ecological system-level approaches are possible. If the latter, what are those approaches? What about umbrella species? Can they be managed as proxies for whole sets of other species and their habitats?

    - Examine properties of species assemblages (such as species-area relationships and ecosystem functioning) with the purpose of developing some of them to measure whether managers have reasonable system-wide diversities.

    - Seek resources of other agencies and institutions that may be leveraged to assist in designing management strategies.

    - Develop tools for evidence-based conservation or adaptive management. These might include databases or other tools to permit installation managers to share approaches and progress in real time.

8.8 PROVIDING THE INFRASTRUCTURE SUPPORT FOR RESEARCH AND MANAGEMENT IN THE SOUTHWEST

Background

Researchers and managers can gain efficiencies and better learn from past experiences, both successful and unsuccessful, when information and tools are centrally archived in a manner that preserves information integrity, establishes consistency, and facilitates accessibility to a wide range of information and tools. A need exists to assemble, integrate, manage, protect, and distribute natural resources research, monitoring, and management data so they may be used effectively to achieve conservation goals across the region. Infrastructure support is needed to efficiently monitor and manage critical southwestern ecosystem states and processes, including community composition and function, TER-S, water resources, and invasive species. Infrastructure support must be sufficiently robust to incorporate multiple spatial and temporal scales and to enable efficient exchange of information across arbitrary institutional boundaries. Infrastructure needs for the Southwest potentially include data and document repositories, decision-support tools, and archival documentation of conservation action successes and failures to support evidence-based conservation for the region. Infrastructure support initiatives should allow feedback between scientists and managers, address multiscalar applications recognizing spatial and temporal variability, and ensure sensitivity of models to predict and reflect landscape conditions.

Significance

DoD installations in the Southwest contribute significantly in providing habitat and management for a broad range of TER-S. Data collected on DoD installations and information on the response to management actions has regional significance for southwestern species recovery and conservation objectives. Likewise, data and lessons learned from non-DoD management initiatives will impact land management objectives and approaches on DoD lands. Efficient interagency data management and accessibility capabilities are a multiplier for return on investment in terms of natural resource management objectives. Efficient infrastructure support reduces redundancies in data collection and management actions, and reduces risk and cost by providing the capability to quickly integrate successful experimental management approaches into practice.

Recommendations

Current barriers to effective use and access to data for southwestern natural resources research and management include a lack of integrated interagency databases, data collected at different spatial and temporal resolution, and analytical tools and approaches necessary to efficient data mining and analyses of diverse data sources. The objective of providing infrastructure support is not to impose rigid data requirements and prescriptive data collection approaches. Rather, the objective is to provide a flexible and adaptive support structure with the broadest accessibility, one that is organic to a broad spectrum of agency and academic research and management programs. Some issues that will need to be resolved to implement the following recommendations include identifying host organization(s) for developed systems, funding sources, intellectual property rights for widely accessible data, and access rights availability for sensitive data. Specific recommendations include:

- Catalog ongoing I&M activities on and around installations, and identify appropriate mechanisms for communicating and making this information generally available (e.g., regional workshops). A potential mechanism for providing workshop support would be through the Desert Southwest, Colorado Plateau, and Great Basin CESUs.
- Develop guidance for implementing and evaluating research and management activities in an evidence-based conservation framework.
- Develop standardized system for securing and moving resources between agencies.
- Develop tools for interagency information management and synthesis. In support of these tools, develop guidance for sharing lessons learned at the intra- and inter-installation and interagency scales.
- Improve research simulation and modeling capabilities for forecasting future conditions or trends.

- Develop decision-support tools that provide land managers the capability to evaluate different alternatives in an adaptive management, evidence-based framework, as well as relevant training programs in their use.

- Consider that a potential mechanism for providing centralized infrastructure support incorporating the previous recommendations would be through the Desert Southwest CESU as a flagship project.

8.9 MONITORING THE STATUS OF SOUTHWESTERN ECOLOGICAL SYSTEMS AND SPECIES

Background

Understanding the condition of resources on DoD lands throughout the southwestern United States is fundamental to the ability to manage those lands for military use, while still complying with legal requirements for the preservation of natural and cultural resources. An accurate assessment of ecosystem resources can only be obtained with information from an integrated ecosystem monitoring program. This program can be realized only by working with other agencies and the public to resolve the often conflicting goals of 'preservation' versus 'use' of ecosystem resources.

For years scientists have sought a way to characterize and determine trends in the condition of ecosystem resources through monitoring protected areas. This has been done in an effort to properly assess the efficacy of ecosystem management practices and restoration efforts and to provide an early warning of impending threats. The challenge of protecting and managing natural resources requires a multi-agency ecosystem approach because most DoD facilities, although generally closed to public use, are parts of larger ecosystems that are vulnerable to air and water pollution, invasive species, and a myriad of other threats originating from outside the boundaries of the individual management unit. Moreover, all managed lands contain numerous organisms that freely move across anthropogenically imposed unit management boundaries. An ecosystem approach to monitoring is needed because no single spatial or temporal monitoring scale is appropriate for all system components and processes. The appropriate scale for understanding and effectively managing a resource might be at the population, species, community, or landscape level and, in some cases, may require a regional, national, or international effort to understand and manage that resource. It is increasingly recognized that military installations are part of larger ecosystems and thus must be managed in that context.

Significance

Resource monitoring provides site-specific information needed to understand and identify change in complex, variable, and imperfectly understood natural systems. Results of monitoring programs better allow managers to determine whether observed changes are within natural levels of variability or may be indicators of unwanted human influences. Thus, monitoring provides a basis for understanding and identifying meaningful change in natural systems characterized by complexity, variability, and stochastic events. Monitoring data help to define the normal limits of natural variation in ecosystem resources and provide a basis for understanding observed changes. Monitoring results may also be used to determine what constitutes impairment and to identify the

need to initiate or change management practices. Understanding the dynamic nature of how DoD lands fit into larger ecosystems and the consequences of training activities is essential for DoD decision-making aimed to maintain, enhance, or restore the ecological integrity of installation ecosystems and to avoid, minimize, or mitigate ecological threats to these systems.

Every monitoring effort must realize that an integral relationship exists between attributes, indicators, and monitoring. Attributes are any living or nonliving feature or process of the environment that can be measured or estimated and that provide insights into the state of the ecosystem. The term ‘indicator’ is reserved for a subset of attributes that is particularly information-rich in the sense that their values are somehow indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon, 2003). Indicators are also a selected subset of the physical, chemical, and biological elements and processes of natural systems that are selected to represent the overall health or condition of the ecosystem. Monitoring then provides the dimension of time, and the general purpose of monitoring is to detect changes or trends in resources over time.

Natural resource monitoring is conducted primarily for two purposes: (1) to detect significant changes in resource abundance, condition, population structure, or ecological processes or (2) to evaluate the effects of some ecosystem management action (e.g., prescribed fire) on resources and the population or community dynamics or ecological processes. Monitoring should always have a specific purpose and provide information that is a prerequisite for management action, which is triggered when values reach or exceed some predetermined threshold value.

The intent of any monitoring program should be to track a subset of physical, chemical, and biological elements and processes of their ecosystems. The selected elements should be chosen in a way to be representative of the overall health or condition of ecosystem resources, known or hypothesized effects of stressors, or elements that have important needs to managers within and outside the ecosystem. The elements and processes (indicators) that are monitored are a subset of the total suite of natural resources that managers are directed to conserve, while providing the ability to maintain the long-term health and stability of the ecosystem. The monitoring components (attributes) should include, but not be solely limited to, water, air, geological and archeological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources.

In situations where natural areas within an ecosystem have been so highly altered that physical and biological processes no longer operate (e.g., control of fires and floods in developed areas), information obtained through monitoring can assist managers to understand how to develop the most effective approach to restoration or, in cases where restoration is impossible, ecologically sound management. The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for decision-making, research, education, and promoting public understanding of DoD lands in the ecosystem framework and large-scale preservation of resources.

Defining elements of a regional monitoring program that are reasonable yet robust enough to measure change within the major ecological systems of the Southwest should address all of the following questions:

- What are the criteria for determining specific metrics to measure?
- Can reference areas be established for each of the major ecological systems of the Southwest?
- How should landscape metrics be monitored over time?
- How applicable is a particular approach to different geographic regions?
- How should partners be engaged to participate in the design of such a program?
- What Historic Range of Variability (HRV) assessments have been done as a baseline for anticipating, detecting, understanding, and managing for change, and how applicable are those assessments under projected climate change scenarios?

Recommendations

As SERDP, ESTCP, and Legacy design and implement their resource monitoring programs, they should focus on two levels: (1) the ecosystem level and (2) the individual installation level. Each installation, in consultation with appropriate disciplinary experts, needs to be encouraged to select its own set of indicators to monitor, along with those of the larger ecosystem. This is important because the relevance of monitoring results needs to be clear to on-the-ground practitioners to facilitate making sound management decisions. For example, monitoring indicators selected by installations may include elements that were selected because they have important human values (e.g., harvested or endangered species) or because of some known or hypothesized threat or stressor/response relationship with a particular installation training action. But it should also be made clear that some monitoring will be dictated by considerations on a larger ecosystem scale beyond the installation.

Specific action items that SERDP, ESTCP, and Legacy should consider supporting in the Southwest follow:

- Convene a regional symposium on TER-S monitoring and develop a proceedings document from that meeting.
- Initiate an effort to catalogue all ongoing inventory and monitoring activities within southwestern ecosystems.
- Establish a national-level proponent to support the Southwest monitoring effort.
- Establish a standard monitoring protocol and data management-storage system for monitoring data.
- Identify all partners that should be part of the Southwest ecosystem monitoring effort.
- Develop decision-support tools that support multiscalar applications and that recognize the spatial and temporal variability of monitoring data.
- Use information science technologies to enhance the user’s ability to interact with monitoring data.

- Establish a working group that identifies collaborative partners and designs a regional monitoring program that will be robust enough to measure change within each of the major southwestern ecosystems.
- Develop economic indicator metrics of ecological services.
- Establish long-term monitoring locations and reference species at the ecoregional level.
- Design, test, and evaluate all proposed monitoring protocols.
- Begin a training program on the use and implementation of monitoring tools.
- Support a study that identifies the value of southwestern DoD lands to ecosystem efforts, maintaining species diversity, and other ecological services.
- Develop monitoring efforts at the ecoregional and individual installation levels. The following regional metrics should be part of this effort:
    - Water budget
    - Phenophases of species
    - Biodiversity of native species
    - Non-native species contribution (i.e., impacts to biodiversity)
    - Ecosystem-service measures
    - Fire frequency, intensity, and spatial distribution by vegetation type
    - Species movement patterns, habitat loss, fragmentation
    - Soil erosion and disturbance
    - Pathogen and vector distributions
    - Landscape change, historic variability, and trajectory

By instituting the above recommendations, DoD will be better equipped to determine the status and trends of its resources, from the individual installation up to the ecosystem level. Selected indicators of the condition of resources within each installation, along with large-scale ecosystem indicators, will enable managers to make better-informed decisions and to work more effectively with other agencies and managers for the benefit of the resources.

An effective long-term ecosystem monitoring program will:

- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of future management.
- Provide data to better understand the dynamic nature and condition of ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet legal and Congressional mandates related to resource protection.
- Provide a means of measuring progress towards performance goals.
- Enable DoD managers to make better informed management decisions.

- Provide early warning of changing conditions in time to develop effective mitigation measures.
- Provide data and information that will facilitate working with other agencies and land managers to reach consensus and make decisions that benefit all partners within the ecosystem.
- Satisfy legal mandates.
- Provide reference data for comparison among DoD lands and with other managed lands within that ecosystem.

8.10 ESTABLISHING AND IMPLEMENTING EFFECTIVE PARTNERSHIPS

Background

Partnership in the conservation and management of natural resources on DoD lands is a longstanding historical practice and norm. In part, this is a result of congressional intent as codified in the Sikes Act of 1960 and its successor, the Sikes Improvement Act of 1997. These mandate cooperation with and the concurrence of (i.e., partnership) the USFWS and the affected state wildlife agency in developing and implementing installation INRMPs. These INRMPs become the documents that direct natural resources management, including TER-S conservation efforts and activities at the installation level. Another example, relevant to the Southwest, is the Military Lands Withdrawal Act of 1999, which in part establishes an interagency advisory council (i.e., partnership) to coordinate conservation management of the Barry M. Goldwater Range.

Although these examples demonstrate a congressional intent for intergovernmental partnering for natural resources on DoD lands, the real impetus for partnering lies in the shared interests between DoD resource managers and a wide variety of federal, state, and local natural resource management agencies and NGOs. This is especially true in the western United States, given the geographical juxtaposition of Defense lands with other federal lands such as BLM Public Lands and Monuments, National Forests, NPS Parks and Monuments, and USFWS National Wildlife Refuges. Resource management issues, concerns, and opportunities almost always cross jurisdictional boundaries. It is rare for a natural resource issue to occur solely within the boundaries of an installation. Opportunities nearly always exist to address stewardship needs in concert with other natural resource management organizations and agencies as well as adjacent jurisdictions. It is also likely that the complexities of resource management cross multiple disciplines—the sciences, management, planning—and that partnerships provide the best means with which to address them.

Significance

DoD lands are of vital importance to a wide variety of TER-S as pressures from an expanding human population and development disproportionately threaten the ecological systems and habitats of the Southwest. Collaborative efforts to conserve, manage, and restore TER-S populations are of national significance, as exemplified by actions taken under the Endangered Species Act. Collaborative efforts of partners at a variety of hierarchical scales, such as local,

regional, and national scales, are essential to the execution of successful TER-S conservation efforts, as well as biodiversity maintenance in general. By helping to fulfill TER-S conservation, collaborative efforts can have significant implications for the achievement of the military mission on DoD lands. Such efforts lead to the restoration of at-risk populations, lead to the recovery of listed species, and also keep common species common. They help to reduce impacts to the DoD mission while contributing vitally to the conservation of the nation's wildlife resources.

Frankly, it is not difficult to defend the importance of partnerships to address TER-S management. What is significant is the challenge to effectively build and sustain them. Too often, partnerships rely on inconsistent and insufficient funding and support. In many cases, they are dependent on the inspirational charisma of one or two key members putting them at risk once leadership changes. Many efforts, such as this current DoD effort, will first sponsor a TER-S partnering workshop and provide support at the onset of partnerships, but they do not necessarily attend to a partnership's infrastructure and long-term needs. In addition, many efforts, such as this one, will focus on funding for new ecological research for ecological systems and associated TER-S, but not on the socioeconomic dimensions of what effective partnerships entail. These latter efforts, however, are vital to effective partnerships and are long overdue in getting the focus they deserve.

Recommendations

DoD and other natural resource managers in the Southwest should evaluate basic business processes for opportunities for partnerships to resolve TER-S and other natural resource conservation-related issues. Partnerships can take many forms and meet different needs. As a result, multiple types of partnerships are needed. Specific recommendations include:

- ***Identify or develop fiscal and administrative models that enable efficient long-term, jointly funded, multi-jurisdictional (federal/state/local/private) partnership efforts and conservation actions***. The network of CESUs may provide an initial model for such an endeavor. This effort should consider the development of congressional enabling legislation that is designed to reduce institutional constraints to resource sharing. DoD policy and regulations should also be considered as means to institutionalize partnerships as solutions for TER-S and other stewardship responsibilities.

- ***DoD and other natural resource managers in the Southwest should consider increasing their investment in the Desert Southwest CESU, which can serve to encourage innovative research springboards and partnership demonstration projects***. The Desert Southwest CESU infrastructure—national network, administrative support, and existing agreements—ideally pre-positions it to serve as a partnership solution to TER-S in the region.[10] However, there are several concerns that should be resolved. Especially significant for TER-S is that both USFWS and the responsible state agency should be members in the regional CESUs. Currently, this is only true for the Great Basin CESU. Another issue—and

[10] Refer to www.cesu.org for additional information.

perhaps opportunity—is the 5-year term limit on CESU agreements in which real collaboration and progress must be demonstrated to gain renewal. These reauthorizations provide for group introspection and evaluation of the CESU 'strengths and weaknesses, threats and opportunities' (known as a SWOT analysis). DoD and its CESU partners should use the SWOT process as a means to assess itself to ensure that the CESU fulfills its region's land management needs by providing the best mix of expertise and leadership. In any case, CESUs should seek always to empower inter-organizational collaboration and innovative problem solving to live up to their potential to improve scientific understanding and management of land and resources.

- ***DoD and other natural resource managers in the Southwest should assess the DoD-wide requirement for the development and implementation of INRMPs as an opportunity to go beyond the existing tri-partite partners specified in the Sikes Act and consider including other vested partnerships in INRMP planning and execution***. Exploration of an INRMP's use as a platform to respond to TER-S management needs at the installation/local, regional, national, and international scales is needed. Opportunities for integrating the INRMP within the planning processes of TER-S partners should be considered.

- ***As a needs assessment to focus initiatives to improve partnering, examine factors that influence varying rates of partnering at different installations***. Potential independent variables include funding and personnel resourcing, training and education level of natural resource managers, regional regulatory and environmental activism contexts, type of military training activities, and the nature and extent of installations' natural resources.

- ***Develop and provide standardized training on partnerships for personnel through courses, 'how to' manuals, and other media*** to enhance chances for success, reduce friction and inertia, and accelerate the achievement of performance goals.

- ***As a research recommendation, investigate new tools in data management and analysis, communication, and information processing that can function as a common portal and clearinghouse for a partnership's knowledge base and business processes***. The Mojave Desert Ecosystem Project (http://www.mojavedata.gov) is an example of one such effort.

- ***Address the need for administrative support, which is frequently under-resourced, to ensure continuous and consistent information routing, including the scheduling of meetings, preparation of minutes, and the tracking and documentation of outputs***. Fiscal support opportunities should be established to contribute to improved function of key partnering efforts. The lessons learned at the White House Conference on Cooperative Conservation (http://cooperativeconservation.gov/) are potential resources for DoD and partners to use in resolving these issues.

- ***The development of multi-hierarchical partnerships should be encouraged by building in a competitive funding advantage for those proposals that can demonstrate a direct metric-driven linkage to other existing plans and partnerships that function at differing levels of scope***.

- Although partnership teams are much improved on interagency and jurisdictional diversity (and rewarded as such in the weighting for funding competitiveness), they often lack interdisciplinary diversity. ***Funding incentives for cross-disciplinary teams should be developed to leverage more innovative and robust approaches to answering natural resource management questions and challenges***. For example, teaming with NGOs that have a long history of making maximum use of interdisciplinary approaches (such as The Nature Conservancy) could be beneficial in helping to increase interdisciplinary diversity.

- ***Encourage the creation of an executive level oversight team to assist struggling partnership efforts and help them resolve ongoing impediments to partnership performance***.

9.0 SUMMARY AND CONCLUSIONS

A primary objective for the Southwest Region TER-S Workshop was to help inform DoD how best to invest its limited conservation resources. By bringing together relevant managers and researchers from various sectors, it is hoped that outcomes from this workshop will create a common platform among federal, state, and non-governmental organizations for future research, demonstration, and management action that benefits TER-S, their associated ecosystems, and the sustainment of training and testing operations.

Workshop participants identified several topics of particular importance for TER-S management in the Southwest. These included how fire, invasive species, habitat fragmentation, and other factors exacerbate habitat and species management challenges, as well as how little is known about dry wash systems. Further, it was suggested that both researchers and managers need to not only focus on efforts to combat the effects of global climate change, but to also learn to adapt to these conditions as the new norm. A general consensus emerged that improving existing partnerships and forming new alliances can provide synergistic benefits to all stakeholders.

By implementing workshop outcomes outlined in the Executive Summary and detailed in Section 8.0, DoD can help address TER-S management challenges by targeting its program dollars towards conservation efforts that achieve species and habitat protection goals while maximizing training and testing flexibility. By removing the threats that impair at-risk species, recovering listed species, and using an ecosystem-based adaptive management approach that considers ecological processes as well as multiple spatial and temporal scales, DoD’s conservation programs strive to keep common species common while preventing the need for additional species listings. Advancing research priorities and using resulting information to better manage listed and at-risk species offers a significant opportunity to benefit TER-S populations in the future. Working together, SERDP, ESTCP, and Legacy strive to tackle conservation challenges holistically, comprehensively, and proactively.

Although no one group or agency can undertake all the actions enumerated in this document, recommendations captured are relevant to many stakeholders. Therefore, these proceedings should be viewed as a source document when prioritizing annual planning and resource allocation activities. Overall, it is hoped that workshop outcomes will prove valuable for multiple interested stakeholders throughout the Southwest for the next several years.

10.0 REFERENCES

Barnett, T. P., Pierce, D.W., Hidalgo, H. H., Bonfils, C., Santer, B.D., Das, T., et al. (2008). Human-induced changes in the hydrology of the Western United States. *Science*, published online 31 Jan 2008, doi:10.1126/science.1152538.

Barnett, T. P. & Pierce, D.W. (2008). When will Lake Mead run dry. *Water Resources Research*, in press.

Bowers, J.E. (2007). Has climatic warming altered spring flowering date of Sonoran Desert shrubs. *Southwestern Naturalist*, *52*, 347-355.

Breshears, D.D., Cobb, N.S., Rich, P.M., Price, K.P., Allen, C.D., Balice, R.G., et al. (2005). Regional vegetation die-off in response to global-change-type drought. *Proceedings of the National Academy of Sciences*, *102*, 15144-15148.

Cayan, D.R., Kammerdiener, S.A., Dettinger, M.D., Caprio, J.M., & Peterson, D.H. (2001). Changes in the onset of spring in the western United States. *Bulletin of the American Meteorological Society*, *82*, 399-415.

Del Rosario, R.B. & Resh, V.H. (2000). Invertebrates in intermittent and perennial streams: Is the hyporheic zone a refuge from drying? *Journal of the North American Benthological Society*, *19*(4), 680-696.

Diffenbaugh, N.S., Pal, J.S., Trapp, R.J., & Giorgi, F. (2005). Fine-scale processes regulate the response of extreme events to global climate change. *Proceedings of the National Academy of Sciences*, *102*(44), 15774-15778.

England A.S. & Laudenslayer, W.F. Jr. (1995). Birds of the California Desert. In J. Latting & P.G. Rowlands (Eds.), The California Desert: An Introduction to Natural Resources and Man's Impact (Vol 2). Riverside, California: June Latting Books.

Hoerling, M.P. & Eischeid, J. (2007). Past peak water in the Southwest. *Southwest Hydrology, 6*, 18–19, 35.

Homer, C., Huang, C., Yang, L., Wylie, B., & Coan, M. (2004). Development of a 2001 national landcover database for the United States. *Photogrammetric Engineering and Remote Sensing*, *70*(7), 829-840.

IPCC (Intergovernmental Panel on Climate Change). Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability Summary for Policymakers. April 6, 2007.

Johnson, R.R. & Haight, L.T. (1985). Avian use of xeroriparian ecosystems in the North American warm deserts. Riparian Ecosystems and Their Management: Reconciling

Conflicting Uses. *First North American Riparian Conference, April 16-18, 1985*. U.S.D.A. Forest Service General Technical Report RM-120, pp. 156-160.

Jones, K.B. (1988). Distribution and habitat associations of herpetofauna in Arizona: Comparisons by habitat type. Management of Amphibians, Reptiles, and Small Mammals in North America. *Proceedings of the Symposium, July 19-21, 1988*. U.S. Forest Service General Technical Report RM-166. pp. 109-128.

Kepner, W.G. (1981). Small mammals of the Black Canyon and Skull Valley Planning Units, Maricopa and Yavapai Counties, Arizona. U.S. Bureau of Land Management, Phoenix District Office. Technical Note 350.

Kirkpatrick, C., Conway, C.J., & LaRoche, D. (2007). Quantifying impacts of groundwater withdrawal on avian communities in desert riparian woodlands of the southwestern U.S. USGS Arizona Cooperative Fish & Wildlife Research Unit, Department of Defense, Legacy Resource Management Program, Project 06-290.

Knowles, N., Dettinger, M.D., & Cayan, D.R. (2006). Trends in snowfall versus rainfall in the western United States. *Journal of Climate*, *18*, 4, 545-4, 559.

Marshall, R., List, M., & Enquist, C. (2006). Ecoregion-based conservation assessments of the southwestern United States and northwestern Mexico: A geodatabase for six ecoregions, including the Apache Highlands, Arizona-New Mexico mountains, Colorado Plateau, Mojave Desert, Sonoran Desert, and Southern Rocky Mountains. Prepared by The Nature Conservancy, Tucson, AZ. 37 pp. Available at www.azconservation.org.

Marshall, R.M., Anderson, S., Batcher, M., Comer, P., Cornelius, S., Cox, R., et al. (2000). *An ecological analysis of conservation priorities in the Sonoran Desert ecoregion.* Prepared by The Nature Conservancy Arizona Chapter, Sonoran Institute, and Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora with support from Department of Defense Legacy Program, Agency and Institutional partners. 146 pp.

McCabe, G.J., & Wolock, D.M. (2007). Warming may create substantial water supply shortages in the Colorado River basin. *Geophysical Research Letters*, *34*, L22708, doi:10.1029/2007GL031764.

Milly, P.C.D., Betancourt, J.L., Falkenmark, M., Hirsch, R.H., Kindzewicz, Z., Lettenmaier, D.P., Stouffer, R.J. (2008). Stationarity is dead: Whither water management — Rethinking approaches to planning and design in a changing climate. *Science*, *319*, 573-574.

Morin, X. & Chuine, I. (2005). Sensitivity analysis of the tree distribution model Phenofit to climatic input characteristics: Implications for climate impact assessment. *Global change Biology*, *11*, 1493-1503.

Mote, P.W., Hamlet, A.F., Clark, M.P., & Lettenmaier, D.P. (2005). Declining mountain snowpack in western North America, *Bulletin of the American Meteorological Society, 86*, 39–49.

Noon, B. R. (2003). Conceptual issues in monitoring ecological resources. In D.E. Busch and J.C. Trexler (Eds.), *Monitoring Ecosystems: Interdisciplinary Approaches for Evaluating Ecoregional Initiatives* (pp. 27-72). Washington, DC: Island Press.

Prior-Magee, J.S., Boykin, K.G., Bradford, D.F., Kepner, W.G., Lowry, J.H., Schrupp, D.L., et al. (2007). Southwest Regional Gap Analysis Project Final Report. U.S. Geological Survey, Gap Analysis Program, Moscow, ID. http://fws-nmcfwru.nmsu.edu/swregap.

Ricketts, T.H., Dinerstein, E., Olson, D.M., Loucks, C.J., Eichbaum, W., DellaSala, D., et al. (1999). Terrestrial ecoregions of North America: a conservation assessment. Washington, DC: Island Press. http://worldwildlife.org/science/ecoregions/delineation.cfm.

Rosen, P.C. & Lowe, C.H. (1996). Ecology of the amphibians and reptiles at Organ Pipe Cactus National Monument, Arizona. Tech. Report #53. Cooperative Park Studies Unit, The University of Arizona, Tucson, AZ.

Seager, R., Ting, M.F., Held, I.M., Kushnir, Y., Lu, J., Vecchi, G., et al. (2007). Model projections of an imminent transition to a more arid climate in southwestern North America. *Science*, *316*, 1181 – 1184.

Steinitz, C., Arias, H., Bassett, S., Flaxman, M., Goode, T., Maddock III, et al. (2003). Alternative Futures for Changing Landscapes: The Upper San Pedro River Basin in Arizona and Sonora. Washington, DC: Island Press.

Stewart, I., Cayan, D., & Dettinger, M.D. (2005). Changes towards earlier streamflow timing across western North America. *Journal of Climate*, *18*, 1, 136-1, 155.

Stromberg, J.C., unpublished data, Arizona State University.

Turner, R.M., Bowers, J.E., & Burgess, T.L. (1995). *Sonoran Desert Plants: An Ecological Atlas*. Tucson: University of Arizona Press. (http://wwwpaztcn.wr.usgs.gov/atlas/).

U.S. Geological Survey (USGS). (2006). National Hydrography Dataset website, http://nhd.usgs.gov/index.html.

Weiss, J.L. & Overpeck, J.T. (2005). Is the Sonoran Desert losing its cool? *Global Change Biology, 11*, 2065-2077.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., & Swetnam, T.W. (2006). Warming and earlier spring increases western U.S. forest wildfire activity. *Science*, *313*, 940-943.

Whiles, M.R. & Goldowitz, B.S. (2005). Macroinvertebrate communities in central Platte River wetlands: Patterns across a hydrologic gradient. *Wetlands*, *25*(2), 462–472.

APPENDIX A
PARTICIPANT LIST

Name	Title	Organization	Email
Averill-Murray, Roy	Desert Tortoise Recovery Coordinator	US Fish and Wildlife Service	Roy_Averill-Murray@fws.gov
Barrows, Cameron	Assistant Research Ecologist	University of California, Riverside	cbarrows@ucr.edu
Betancourt, Julio	Project Chief, National Research Program, Water Resources Division	US Geological Survey	jlbetanc@usgs.gov
Boice, Peter	DoD Conservation Team Leader	DoD Legacy Resource Management Program	peter.boice@osd.mil
Braunstein, Karole	Workshop Staff	HydroGeoLogic, Inc.	kbraunstein@hgl.com
Briggs, Mark	Restoration Biologist	World Wildlife Fund	mkbriggs@msn.com
Brooks, Matt	Research Botanist	US Geological Survey	matt_brooks@usgs.gov
Burkett, Doug	Natural and Cultural Resources Program Manager	Air Force, Headquarters	Douglas.burkett@pentagon.af.mil
Childress, Bill	National Conservation Area Manager	Bureau of Land Management	bill_childress@blm.gov
Dalsimer, Alison	Workshop Staff	HydroGeoLogic, Inc.	adalsimer@hgl.com
Doe, William	Watershed Hydrologist for CEMML (Center for Environmental Management of Military Lands)	Colorado State University	William.Doe@ColoState.edu
Donahoe, Sean	Workshop Staff	HydroGeoLogic, Inc. (subcontractor)	sd@marstel-day.com
Duffy, Amy	Managing Member	Office of the Deputy Under Secretary of Defense (I&E) –Contractor	amyduffy@duffyconsulting.net
Dye, Jeanne	Natural Resources Manager	Holloman AFB (Alamogordo, NM)	jeanne.dye@holloman.af.mil
Esque, Todd	Ecologist	US Geological Survey	todd_esque@usgs.gov
Everly, Clarence	Program Manager	Mojave Desert Ecosystem Program	everlyc@mojavedata.gov
Fernandez, Erin	Fish and Wildlife Biologist	USFWS, Tucson Ecological Services Sub Office	Erin_Fernandez@fws.gov
Finch, Deborah	Research Wildlife Biologist	USDA Forest Service Rocky Mountain Research Station	dfinch@fs.fed.us

Name	Title	Organization	Email
Goode, Matt	Research Scientist for Wildlife Conservation and Management	University of Arizona	mgoode@ag.arizona.edu
Gorman, Lewis	DoD/FWS TE Liaison	US Fish and Wildlife Service	Lewis_Gorman@fws.gov
Gottfried, Jerry	Research Forester	USDA Forest Service Rocky Mountain Research Station	ggottfried@fs.fed.us
Graumlich, Lisa	Director, School of Natural Resources	University of Arizona	lisag@cals.arizona.edu
Grossi, Bill	Wildlife Biologist	Bureau of Land Management	bill_grossi@blm.gov
Hall, John	Sustainable Infrastructure Program Manager	SERDP/ESTCP	john.hall@osd.mil
Hare, Trevor	Conservation Biologist	Sky Island Alliance	trevor@skyislandalliance.org
Harmon, Russell	Senior Program Manager for Terrestrial Sciences Environmental Sciences Division	US Army Research Office	Russell.Harmon@us.army.mil
Hautzinger, Andrew	Hydrologist	US Fish and Wildlife Service	andrew_hautzinger@fws.gov
Hayden, Tim	Program Manager for the U.S. Army Endangered Species Research Program	U.S. Army Engineer Research and Development Center	timothy.j.hayden@erdc.usace.army.mil
Helfert, Steven	DoD Liaison	US Fish and Wildlife Service	steve_helfert@fws.gov
Henen, Brian	Ecologist & Project Manager, Tortoise Research and Captive Rearing Site	Twentynine Palms MCAGCC	brian.henen@usmc.mil
Hodapp, Steve	Endangered Species Program Manager	Bureau of Land Management	steve_hodapp@blm.gov
Holck, Alan	Chief	US Air Force, Range and Airspace Environmental, Air Combat Command	alan.holck@langley.af.mil
Howe, Susan	Civil and Environmental Engineering	Colorado State University	showe@lamar.colostate.edu
Hughson, Debra	Science Advisor, Mojave National Preserve	National Park Service	Debra_Hughson@nps.gov
Ingraldi, Mike	AZ Natural Heritage Team	Arizona Department of Game and Fish	mingraldi@cybertrails.com

Name	Title	Organization	Email
Ivanyi, Craig	General Curator, Curator of Herpetology, Ichthyology & Invertebrate Zoology	Arizona-Sonora Desert Museum	civanyi@desertmuseum.org
Kepner, Bill	Research Ecologist, Landscape Ecology Branch	Environmental Protection Agency	kepner.william@epa.gov
Levick, Lainie	Senior Research Specialist	USDA Agricultural Research Service, Tucson	Lainie.levick@ars.usda.gov
Lister, Ray	Supervisory Natural Resource Specialist	Bureau of Land Management	Ray_Lister@blm.gov
Locke, Brian	Wildlife Biologist	U.S. Army, Fort Bliss	brian.a.locke@us.army.mil
Magathan, Kelly	Workshop Staff	HydroGeoLogic, Inc.	kmagathan@hgl.com
Mallory, Jane	Natural Resource Management Specialist	DoD Legacy Resource Management Program	jane.mallory.ctr@osd.mil
Marshall, Rob	Director of Science	The Nature Conservancy--Arizona	rmarshall@tnc.org
Mathis, Patrick	Southwest Area Game Manager and Habitat Specialist	New Mexico Department of Game and Fish	pmathis@state.nm.us
McIntyre, Cheryl	Ecologist	Sonoran Institute	cmcintyre@sonoran.org
McPherson, Guy	Professor of Natural Resources and Ecology & Evolutionary Biology	University of Arizona	grm@ag.arizona.edu
Moore, Jim	Mojave Desert Ecoregional Ecologist	The Nature Conservancy--Nevada	jmoore@tnc.org
Morrill, Val	Sustainable Range Program Manager (Retired)	U.S. Army, Yuma Proving Ground	bebbia@hotmail.com
Mouat, Dave	Associate Research Professor Division of Earth and Ecosystem Sciences	Desert Research Institute	David.Mouat@dri.edu
Orzetti, Leslie	Workshop Staff	HydroGeoLogic, Inc. (subcontractor)	orzetti@ecosystemsolutions.org
Pennix, Steve	Biologist/NEPA Coordinator	U.S. Navy, China Lake Naval Air Weapons Station	steve.penix@navy.mil
Rice, Kathy	Curator of the Rare & Endangered Plants	Desert Botanical Garden	krice@dbg.org
Richards, Laura	Wildlife Diversity Coordinator	Nevada Department of Wildlife	lrichard@ndow.org
Richter, Holly	Upper San Pedro Project Director	The Nature Conservancy--Arizona	hrichter@tnc.org

Name	Title	Organization	Email
Ripley, Doug	Senior Environmental Professional	Engineering-Environmental Management, Inc.	James.Ripley@e2m.net
Rosenzweig, Mike	Professor of Ecology and Evolutionary Biology	University of Arizona	scarab@u.arizona.edu
Rutman, Sue	Plant Ecologist with Organ Pipe Cactus National Monument	National Park Service	sue_rutman@nps.gov
Sarvey, Cornelia	Environmental Scientist	Loiederman Soltesz Associates	CSarvey@lsassociates.net
Schwartz, Lorri	Natural Resource Specialist	Naval Facilities Engineering Command Headquarters (NAVFAC-HQ)	Lorri.Schwartz@navy.mil
Shepard, Alicia	Workshop Staff	HydroGeoLogic, Inc.	ashepard@hgl.com
Sisk, Tom D.	Associate Professor, Ecology	Northern Arizona University Center for Environmental Sciences and Education	Thomas.Sisk@nau.edu
Skroch, Matt	Executive Director	Sky Island Alliance	matt@skyislandalliance.org
Sogge, Mark	Supervisory Ecologist at the Southwest Biological Science Center	US Geological Survey	mark_sogge@usgs.gov
Spicer, Bill	Conservation Program Manager	U.S. Navy, CNIC HQ	william.a.spicer@navy.mil
Steidl, Bob	Associate Professor, Wildlife and Fisheries Science	University of Arizona	steidl@ag.arizona.edu
Stingelin, Angela	Wildlife Specialist	Arizona Department of Game and Fish	angela.stingelin@earthlink.net
Stone, Sheridan	Wildlife Biologist Environmental and Natural Resources Division	Fort Huachuca	sheridan.stone@us.army.mil
Thigpen, Johnathan	Workshop Staff	HydroGeoLogic, Inc.	jthigpen@hgl.com
Thomas, Kathryn	Plant Ecologist	US Geological Survey	kathryn_a_thomas@usgs.gov
Tyburec, Janet	Biologist/ Workshop Instructor	Bat Conservation International	jtyburec@mac.com
Van Devender, Tom	Senior Research Scientist	Arizona-Sonora Desert Museum	tvandevender@desertmuseum.org
Van Riper, Charles	Station Leader for the Sonoran Desert Research Station	US Geological Survey	charles_van_riper@usgs.gov

Name	Title	Organization	Email
Voyles, Larry	Director	Arizona Department of Game and Fish	LVoyles@azgfd.gov
Waldien, Dave	Co-Director of Programs, Conservation Scientist	Bat Conservation International	dwaldien@batcon.org
Whittle, Richard	Wildlife Biologist for Range Management Office	U.S. Army, Luke AFB	Richard.whittle@luke.af.mil
Woodson, Bill	Workshop Staff	HydroGeoLogic, Inc. (subcontractor)	the-woodsons@comcast.net

APPENDIX B
AGENDA

Monday, October 22 - PLENARY SESSION AND PAPER PRESENTATIONS				
Start	**End**	**Topic/Title**	**Speaker**	**Organization**
		Registration Open		
12:30 PM	12:45 PM	Conference Welcome and Announcements	Dr. John Hall Mr. L. Peter Boice	SERDP/ESTCP DoD Conservation, Legacy
12:45 PM	2:00 PM	Overviews: SERDP, ESTCP, Legacy Program	Dr. John Hall Mr. L. Peter Boice	SERDP/ESTCP DoD Conservation, Legacy
2:00 PM	2:30 PM	DoD's Southwestern Regional Partnership Efforts	Ms. Amy Duffy	Office of the Deputy Under Secretary of Defense (I&E)
2:30 PM	3:00 PM	Variability in Southwest Precipitation	Dr. Julio Betancourt	US Geological Survey
3:00 PM	3:30 PM	**Break**		
3:30 PM	4:00 PM	Altered Fire Regimes	Dr. Guy McPherson	University of Arizona
4:00 PM	4:30 PM	Hydrology and Ecology of Intermittent Stream and Dry Wash Ecosystems	Ms. Lainie Levick	USDA Agricultural Research Service
4:30 PM	5:00 PM	Issues of Spatial Scale	Dr. Michael Rosenzweig	University of Arizona
5:30 PM	7:00 PM	**Evening Mixer and Reception**		
Tuesday, October 23 - FIELD TRIP				
Start	**End**	**Topic/Title**		
7:30 AM	8:00 AM	**Continental breakfast**		
8:00 AM		Depart Hotel		
10:15 AM	4:30 PM	Field Tour		
	6:30 PM	Arrive Hotel		
Wednesday, October 24 - TECHNICAL SESSIONS				
Start	**End**	**Topic/Title**	**Chair**	**Organization**
7:30 AM	8:00 AM	**Continental breakfast**		
		Session 1: TER-S Management: Understanding Patterns of Rarity Within an Ecological System Context		
8:00 AM	8:15 AM	Session Charges		
8:15 AM	10:00 AM	1-1: Desert Scrub (Mojave and Sonoran Deserts; little grass; includes relict Desert Grasslands)	Larry Voyles	Arizona Dept of Game and Fish
8:15 AM	10:00 AM	1-2: Semidesert Grasslands (invaded by shrubs) and Chihuahuan Desert	Mark Sogge	US Geological Survey
8:15 AM	10:00 AM	1-3: Woodlands (Sky Islands)	Charles Van Riper	US Geological Survey
8:15 AM	10:00 AM	1-4: Intermittent Streams and Dry Washes (hydrologic pulse driven systems)	Andrew Hautzinger	US Fish and Wildlife Service
10:00 AM	10:15 AM	**Break**		
10:15 AM	12:00 PM	1-1: Desert Scrub (Mojave and Sonoran Deserts; little grass; includes relict Desert Grasslands)	Larry Voyles	Arizona Dept of Game and Fish
10:15 AM	12:00 PM	1-2: Semidesert Grasslands (invaded by shrubs) and Chihuahuan Desert	Mark Sogge	US Geological Survey
10:15 AM	12:00 PM	1-3: Woodlands (Sky Islands)	Charles Van Riper	US Geological Survey

10:15 AM	12:00 PM	1-4: Intermittent Streams/Springs and Dry Washes, (hydrologic pulse driven systems)	Andrew Hautzinger	US Fish and Wildlife Service
12:00 PM	1:30 PM	**Lunch**		
		Session 2: Ecological Processes and Their Variability in Space and Time		
1:30 PM	1:55 PM	Morning sessions report		
1:55 PM	2:00 PM	Session Charges		
2:00 PM	3:15 PM	2-1: Fire Regimes	Matt Brooks	US Geological Survey
2:00 PM	3:15 PM	2-2: Climate Variability and Change	Tim Hayden	US Army Engineer Research and Development Center
2:00 PM	3:15 PM	2-3: Fragmentation	Dave Mouat	Desert Research Institute
2:00 PM	3:15 PM	2-4: Hydrology and Ecology of Southwestern Intermittent Streams, Dry Washes, and Adjacent Riparian Zones	Andrew Hautzinger	US Fish and Wildlife Service
4:30 PM	6:30PM	**Reception and Dinner at Arizona-Sonora Desert Museum**		
Thursday, October 25 - TECHNICAL SESSIONS CONTINUED				
Start	**End**	**Topic/Title**	**Chair**	**Organization**
7:30 AM	8:00 AM	**Continental breakfast**		
8:00 AM	10:00 AM	2-1: Fire Regimes	Matt Brooks	US Geological Survey
8:00 AM	10:00 AM	2-2: Climate Variability and Change	Tim Hayden	US Army Engineer Research and Development Center
8:00 AM	10:00 AM	2-3: Fragmentation	Dave Mouat	Desert Research Institute
8:00 AM	10:00 AM	2-4: Hydrology and Ecology of Southwestern Intermittent Streams, Dry Washes, and Adjacent Riparian Zones	Andrew Hautzinger	US Fish and Wildlife Service
10:00 AM	10:25 AM	**Break**		
10:25 AM	10:55 AM	Morning sessions report		
		Session 3: Monitoring, Management, and Coordination Across Boundaries		
10:55 AM	11:00 AM	Session Charges		
11:00 AM	12:30 PM	3-1: Effects of Spatial Scale	Dave Mouat	Desert Research Institute
11:00 AM	12:30 PM	3-2: Regional Condition Metrics	Larry Voyles	Arizona Dept of Game and Fish
11:00 AM	12:30 PM	3-3: Hierarchical Monitoring	Mark Sogge	US Geological Survey
11:00 AM	12:30 PM	3-4: Partnerships and Information Sharing	Valerie Morrill	Yuma Proving Ground
12:30 PM	1:30 PM	**Lunch**		
		Breakout Session 3: cont.		
1:30 PM	3:15 PM	3-1: Effects of Spatial Scale	Dave Mouat	Desert Research Institute
1:30 PM	3:15 PM	3-2: Regional Condition Metrics	Larry Voyles	Arizona Dept of Game and Fish
1:30 PM	3:15 PM	3-3: Hierarchical Monitoring	Mark Sogge	US Geological Survey
1:30 PM	3:15 PM	3-4: Partnerships and Information Sharing	Valerie Morrill	Yuma Proving Ground
3:15 PM	3:45 PM	**Break**		
3:45 PM	4:15 PM	Morning sessions report		
FORMAL WORKSHOP ENDS				

APPENDIX C
WORKSHOP CHARGE

Southwest Region Threatened, Endangered, and At-Risk Species Workshop:
Managing Within Highly Variable Environments

Sponsors: This event is being sponsored by the Strategic Environmental Research and Development Program (SERDP), Environmental Security Technology Certification Program (ESTCP), and Legacy Resource Management Program (Legacy). SERDP and ESTCP are Department of Defense (DoD) programs designed to support research, development, demonstration, and transition of environmental technologies required by DoD to perform its mission. Sustainable infrastructure, including natural resources, is an important focus area for these programs. Legacy supports DoD efforts to protect, enhance, and conserve our nation's natural and cultural heritage through stewardship, leadership, and partnership while contributing to the long-term sustainability of DoD's land, air, and water resources for military use. All three programs seek to improve DoD's management of natural resources through investments in research, development, demonstration, or management initiatives.

Background: DoD serves as steward for approximately 30 million acres of land. These lands harbor more threatened, endangered, and at-risk species (TER-S) per acre than any other federal lands. DoD is committed to protecting its lands, oceans, and airspace, as well as the native ecosystems and species that inhabit them, and has established a range of policies to ensure proper stewardship while sustaining military mission readiness. Through improved understanding of native ecosystems, TER-S and their habitats, and their relationships to military training activities, DoD can improve its management of military lands to ensure their availability for training and testing and to enhance conservation of our nation's biological diversity. In June 2005, the Department of Defense sponsored a national symposium on issues related to TER-S on DoD lands (http://www.serdp.org/tes/). A major outcome of this event was the determination that regional workshops were needed to develop appropriate research, demonstration, and management agendas.

The military is the responsible land manager for millions of acres of land throughout the Southwest, a region defined for the purposes of this workshop as encompassing the Chihuahuan, Mojave, and Sonoran deserts, the basin and range (semidesert grasslands and sky islands woodlands) transition between the Sonoran and Chihuahuan Deserts, and embedded intermittent and permanent aquatic/riparian ecosystems. Within this region several installations provide critical opportunities for military testing and training. In addition, these same installations provide essential habitat for numerous TER-S, a number of whose conservation needs have been studied extensively at the individual species level (e.g., desert tortoise). The aquatic and terrestrial ecosystems across the region, on which these species depend, have been significantly altered compared to historic amounts and conditions by a variety of anthropogenic stresses that include urbanization, resource extraction, livestock grazing, military activities, and recreational activities. In addition, the region is experiencing a long-term drought that could continue for the next few decades.

To facilitate the recovery of listed species and to mitigate against the need for new listings, increased attention is needed on how to manage listed and at-risk species from an ecological system perspective that encompasses numerous land management jurisdictions throughout the region. Several cooperative efforts are already underway. These include the Mojave Desert Ecosystem Program (www.mojavedata.gov/home.html), which provides a comprehensive, shared scientific database and GIS data clearing house, and the Sonoran Desert Ecosystem Initiative (https://www.denix.osd.mil/denix/Public/Library/NCR/Eco_mgmt/legacy_accomplishments_rev2.doc), a Legacy-funded effort that focused on ecosystem monitoring and coordinated management, integration of

biological and social components into a site-specific biodiversity management framework, and invasive plant management at the landscape scale. These and new efforts would be bolstered by improved understanding of how to manage the natural resources occurring within the arid and semiarid landscapes encompassed by the three deserts above when these landscapes are subject to highly variable precipitation patterns, and not just overall limited water availability, amidst increasing human use of the land and water resources themselves. The TER-S Science Forum, a multi-federal agency working group that includes DoD, U.S. Fish and Wildlife Service, U.S. Geological Survey, U.S.D.A. Forest Service, the Bureau of Land Management, and the U.S. Army Corps of Engineers Engineer Research and Development Center, assists SERDP, ESTCP and Legacy with the development of the regional TER-S workshops. This is in keeping with the Forum's focus on federal natural resource science coordination.

Objective: SERDP, ESTCP, and Legacy must determine how their limited research, demonstration, and management funds can best be invested to improve DoD's ability to effectively address its TER-S management requirements in the Southwest while maintaining the military training mission. To strategically guide future investments, and facilitate long-term cooperation and coordination, this workshop will:

(1) assess TER-S management needs within a regional context with an emphasis on system-level and cross-boundary approaches;

(2) assess these approaches for their potential to keep common species common while recovering or enhancing TER-S populations;

(3) assess current understanding of the ecology of arid and semiarid ecosystems—in terms of understanding the dynamics of highly variable and difficult to predict environments that are also subject to periodic long-term drought—and how that does or should affect management approaches;

(4) examine the current state of practice within DoD for such holistic approaches;

(5) identify the gaps in knowledge, technology, management, and partnerships that if addressed could improve implementation of system-level and cross-boundary approaches; and

(6) prioritize DoD investment opportunities to address these gaps.

Species-specific research, demonstration, and management requirements are not a focus of the workshop.

Approach: This workshop will take place the week of 22 October 2007 in Tucson, Arizona. Invitees to the workshop will include senior researchers and managers from DoD, other federal and state agencies, academia, and the non-governmental organization (NGO) community. Elements of the workshop will include commissioned paper presentations, a field tour of Fort Huachuca, and three technical sessions focusing on TER-S Management, Ecological Processes, and Coordination Across Boundaries.

Product: The outcome of this workshop will be a strategic research, demonstration, and management document that provides recommendations for SERDP, ESTCP, and the Legacy program, as well as other interested parties, to guide TER-S and ecosystem management related investments over the next three to five years.

APPENDIX D
SESSION CHARGES

Session I—TER-S Management: Understanding Patterns of Rarity Within an Ecological System Context

Species associated with a particular ecological system may be rare as a consequence of their unique biology or in response to anthropogenic alterations (direct or indirect) of system processes or, as a particular subset of processes, species interactions. Conservation of naturally rare species may miss the mark if their unique biology and biological relationships are not fully understood and accounted for when management decisions are made. In addition, inappropriate land uses and management actions may negatively exacerbate their population status and place them at-risk. In the arid and semiarid Southwest, aridity and its variability over space and time, especially in the context of climate change, create unique challenges for managing naturally rare species. Conversely, other more naturally abundant or widespread species may be rare, and therefore already at risk, because of anthropogenic alterations of the structure, composition, or function of the habitats they use, alterations of key species interactions, or direct adverse impact on individuals. Impacts at the system level can occur through direct habitat loss, alteration of ecological processes, or the introduction of invasive species. Management response may be more appropriately directed at managing the anthropogenic stressors that are causing the impacts, not only to improve the population status of at-risk species but also to keep currently common species common.

The goal of this session is to identify, within an ecological system context, (1) any patterns of rarity that may need to be defined and understood – that is, what are the data gaps that, if addressed, could enable resource managers to craft effective conservation strategies not only to "recover" species when such species are truly at-risk, but also to keep common species common, including those that are likely to become vulnerable in the future, (2) key anthropogenic stresses (and their sources) that cause species rarity, and (3) potential management responses that should be tested.

Session II—Ecological Processes and Their Variability in Space and Time

Ecological processes and, as a consequence, associated biotic responses have variability in both space and time. Temporal variability is especially critical in the Desert Southwest, in which a change in the frequency of a process may present process-dependent species with unfavorable habitat conditions for periods of time to which they are not adapted. Ephemeral plants, fire-adapted species, and hydrologic regime-dependent species all respond to the natural variability inherent in ecological processes and often negatively to human alterations of such processes, including their variability. Maintaining ecological processes and accounting for their variability (notwithstanding increases in that variability as a result of climate change) is a huge challenge for resource managers in the Southwest. The effects of fragmentation as a process are understood for a few individual species, but a broader understanding is needed of whether fragmentation may cause species or groups of species to fall below critical population levels that negatively affect viability, and whether those levels relate to body size, social structure, dispersal characteristics, and metapopulation dynamics among other factors. Also, the direct effects of fragmentation on ecological processes and how any negative impacts can be mitigated need to be addressed. Many of the key ecological processes in the Southwest have been altered by the introduction of invasive species. Their current impacts, projected trends, and potential mitigation need to be considered.

The goal of this session is to identify the data gaps in knowledge relative to key ecological processes in the Southwest in terms of (1) how they are expressed both spatially and temporally, (2) the consequences of that expression, and (3) how, within a potentially changing environment – due to climate change, potential land-use changes, and the presence of invasive species – such processes may be managed to maintain the biodiversity of the region.

Session III—Monitoring, Management, and Coordination Across Boundaries
This session will identify partnership opportunities, data gaps, and management approaches that can be undertaken and that may lend themselves to research or demonstration. Assessment of the status of the overall biodiversity of a region requires recognition of spatial scale effects when defining appropriate metrics to consider and how such metrics may nest across scales. Resource managers often lack an appropriate context in which to evaluate their own monitoring data to determine whether they are collecting the most appropriate data.

The goal of this session is to (1) assess broadly the type of system-level monitoring data that DoD installations should be collecting, (2) identify how consideration of spatial scale and hierarchical monitoring (nesting of data across scales) affects what data should be collected and how it should relate across scales, (3) identify how DoD-associated monitoring may relate to regional condition metrics, and (4) identify the partnering opportunities that could facilitate coordinated approaches to management of ecological systems in the Southwest, including coordinated approaches to monitoring the ecological status of the region.

APPENDIX E
WHITE PAPERS

Climate Variability and Change in the Southwest
Julio Betancourt

Fire Regimes of the American Southwest
Matthew Brooks and Guy McPherson

Hydrology and Ecology of Intermittent Streams and Dry Wash Ecosystems
Lainie Levick, et al.

Spatial Scale and the Management of Threatened, Rare/Endangered Species
Michael Rosenzweig

Military Land Use: Overview of DoD Land Use in the Desert Southwest, Including Major Natural Resource Management Challenges
Timothy Hayden, William Doe and Robert Lacey

*White Papers are also posted at www.serdp.org/tes/southwest.

Climate Variability and Change in the Southwest

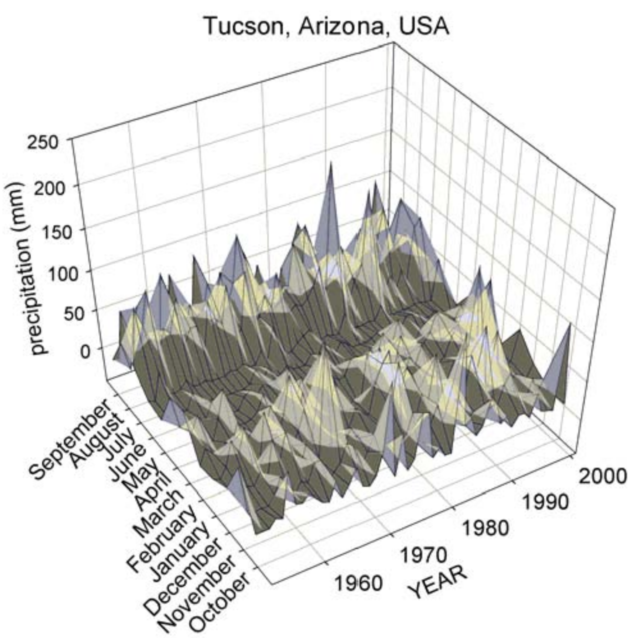
Julio L. Betancourt, National Research Program Water Resources Division U.S. Geological Survey Tucson, AZ.

Introduction

Climate variability and climate change pose significant challenges to land and resource managers, who may or may not have the background or the time to keep up with rapid advancements in both knowledge and technology. This white paper is meant as a supplement to my oral presentation to the DOD Southwest TER-S Workshop on October 22, 2007, which is attached as an appendix. The presentation focuses on (1) patterns of decadal-to-decadal scale precipitation variability and its association with global sea surface temperatures (temperatures in the upper meter of the ocean), and (2) recent findings on how climate change might affect both temperature and precipitation in the Southwest. The white paper provides some additional details, formalizes key questions about ecological responses to climate, and identifies some research needs.

Seasonal and Interannual Precipitation Variability

Over much of the Southwest, seasonal precipitation is characterized by a highly variable winter-early spring (November-March), an arid late spring and foresummer (April-June), monsoonal rains in July and August, and a dry autumn (September-October). The importance of monsoonal rainfall decreases westward, though warm season rainfall still contributes ~46% of the mean annual precipitation at Joshua Tree National Park in eastern California. Occasionally, persistent rainfall events develop in late summer and fall when moisture from dissipating tropical storms is steered inland over several days by low-pressure troughs and cut-off lows. These systems can produce extreme floods, such as tropical storm Octave in October 1983 (Webb and Betancourt 1992). In some years, these fall tropical storms contribute most of the annual rainfall in southwestern Arizona (e.g., Yuma).



Interannual variability in fall, winter and spring precipitation is modulated by the El Nino Southern Oscillation (ENSO), with El Niño's (warming in the central and eastern tropical Pacific) being wet (e.g., 1905, 1940-41, 1957-58, 1965-66, 1972-73, 1977-78, 1982-83, 1987-88, 1992-93, 1994-95, 1997-98, 2005) and La Niña events (1925, 1950-51, 1955-56, 1964-65, 1973-74, 1975-76,1988-1989, 1996-97, 2000-2001) dry. In general, the correlation between La Niña and precipitation deficits is stronger than between El Niño and precipitation surpluses. Stronger teleconnections occur when the temperature anomalies in the tropical Pacific peak in the boreal winter (DJF). Interannual variability in monsoonal precipitation is less clearly tied to large-scale climatic indices like ENSO. Greater detail on interannual variability of Southwest precipitation can be found in Shepard et al. (2002). Due to its frontal character (storm cells ~10^2 wide), cool season precipitation is highly synchronized across large areas, yet quite variable in time. The frontal character of winter precipitation

means that it is highly synchronized across the broader region. Summer precipitation is much patchier in space (storm cells ~10^1 wide), but more predictable in time at any given site. In general, cool season precipitation recharges soil moisture and controls woody plant growth and regeneration, whereas summer rains drive the annual grass production that supports the livestock industry in Arizona and New Mexico.

This varying degree of regional synchroneity in seasonal precipitation is one reason why summer cloudbursts happened this year on your pasture but not on mine; spring wildflower blooms occur simultaneously in the Mojave and Sonoran Desert (Bowers 2005); peak streamflow shifts from summer to winter with increasing size of basin; and area burned tends to track El Niño, La Niña and springtime fuel moisture conditions across the Southwest (Swetnam and Betancourt 1990; 1998). Regional synchroneity in winter precipitation is also the main reason why we can easily crossdate the climate signal in annual ring widths from a ponderosa pine growing on the Mogollon Rim with that of a Douglas fir growing in the Catalina Mountains.

For plants, both recruitment and growth are highly synchronous across the region in species that respond mostly to winter precipitation, much less synchronous for those that respond to summer rainfall. As a first approximation, ecological responses to climate are much easier to extrapolate to the region for winter-responding than summer-responding plants. There are probably functional, if not evolutionary, differences in these two types of plants. One could easily imagine how gene flow is much more enhanced across populations in which phenology and reproductive success are widely synchronized (in winter) vs. populations in which they are not (summer).

Decadal-to-multidecadal-scale (D2M) climate variability

Decadal-to-multidecadal (D2M) variability, characterized by alternating and widespread droughts and pluvials, is a consistent feature of both instrumental and tree-ring records of hydroclimate in the western United States (U.S.). Some notable examples include the dramatic switch from the megadrought in the late 1500s to the megapluvial in the early 1600s, and the bracketing of epic droughts in the 1930s and 1950s by two of the wettest episodes (1905-1920 and 1965-1995) in the last millennium. D2M precipitation variability in the western U.S. tends to be spatially coherent, and can synchronize physical and biological processes in ways that are complex and difficult to forecast and monitor (Swetnam and Betancourt 1998; Siebold and Veblen, 2006; Gray et al., 2006; Kitzberger et al., 2007).

There is growing debate about whether D2M variability in western U.S. hydroclimate represents true climatic regimes - i.e., multiple steady states with different statistics and rapid transitions from one state to the other. Low-order persistence can arise in any time series from stationary red-noise processes, and could be misinterpreted as regimes. D2M variability should not be dismissed summarily, however, based solely on analysis of instrumental records too brief to capture more than a couple of realizations; D2M variability commonly is found in lengthy tree - ring reconstructions. In these reconstructions climatic regimes can be quantified objectively by removing year-to-year persistence in tree growth (e.g., Biondi et al., 2005).

Mechanisms for inducing D2M signals in precipitation over land are poorly understood. Statistical and modeling studies suggest teleconnections to low-frequency sea-surface temperature (SST) variability in the Pacific, Indian, and North Atlantic Oceans (Hoerling and Kumar, 2003; McCabe and Palecki, 2006), and there is debate and mounting interest about mechanisms and predictability (e.g., Collins and Sinha, 2003). In the western U.S. and Great Plains, correlation studies show consistent association of persistent droughts (pluvials) with North Atlantic warming (cooling) and tropical and eastern Pacific cooling (warming) (Enfield et al., 2001; McCabe et al., 2004). Preliminary studies show similar relations between D2M variability in tree-ring reconstructions of precipitation (or the Palmer Drought Severity Index) with

the Pacific Decadal Oscillation (e.g., Biondi et al., 2001) and the Atlantic Multidecadal Oscillation (Gray et al., 2004; 2005; Hidalgo 2004).

Apparent teleconnections are being explored by using atmospheric general circulation models that use historical SST data as a lower boundary condition, simulate low-frequency variations in precipitation over land, and allow attribution of these hydroclimatic variations to specific ocean sectors (Schubert et al., 2004; Seager et al., 2005). Modeling studies have indicated that low-frequency SST variability in the tropical Pacific is paramount but may not operate independently of other oceans. It has been suggested that low-frequency variability of tropical Pacific SSTs is primarily driven by radiative forcing (Clement et al., 1996; Cane and Clement, 1999; Mann et al., 2005), however, direct radiative forcing may not be the only driver of low-frequency variability in tropical Pacific SSTs. A recent study using HadCM3 shows that multidecadal changes in Atlantic SSTs associated with thermohaline circulation (THC) overturning also can modulate variance of the El Nino/Southern Oscillation (ENSO) (Dong et al., 2006; Dong and Sutton 2007; see also Timmerman et al., 2007*)*.

D2M precipitation variability in the western U.S. tends to be spatially coherent, and can synchronize physical and biological processes in ways that are complex and difficult to forecast and monitor. D2M variability can synchronize fluctuations in surface water availability across major basins, and can thus overextend regional drought relief and interbasin transfer agreements. Traditionally, both water resource and floodplain management in the West has been based mostly on stationary assumptions about surface flow- that the mean and moments of the annual or peak discharge distributions do not change over time. Federal flood insurance relies on the concept of the 100-yr flood, which is calculated routinely with flood frequency methods that assume stationarity. And we also assume stationarity in annual operations of critical water resources, for example upper Colorado River Basin streamflow and storage.

In the case of D2M variability, 100 years may not be long enough to evaluate stationary assumptions in water resource planning, and we're forced to rely on tree-ring reconstructions of precipitation and streamflow. These reconstructions vary in coverage and quality, but nonetheless are a good first approximation of the history and long-term probability of D2M precipitation and streamflow regimes. In particular, probability distribution functions from long reconstructions of hydroclimate (precipitation or streamflow) or climatic index series (AMO, PDO, etc.) can be used to calculate the occurrence and return probabilities of climatic episodes (Enfield and Cid-Cerrano 2005). This information can then be mapped to decisions about annual water resource operations or facilities planning.

By synchronizing ecological disturbances and recruitment pulses, D2M variability also plays a key role in structuring woodland and forest communities in western watersheds; it also modulates demographic pulses in desert ecosystems. In the event of longer, hotter growing seasons, D2M variability will still determine the timing and pace of ecosystem changes. Oscillations between warm-dry and warm-wet regimes will continue to produce uncommonly large disturbances followed by accelerated regeneration and succession. A principal challenge for land managers in the 21st century will be to manage for disturbance and succession in purposeful and systematic ways that promote asynchrony and patchiness at local to regional scales, while still preserving goods and services that ecosystems provide.

Temperature and Precipitation Predictions for the Southwest

Global warming due to increase in greenhouse gases due to fossil fuel and land use (specifically, tropical biomass burning) may already be affecting the Southwest. Temperatures in all seasons, as well as the length of the growing season, have already increased and are predicted to continue to increase in the Southwest.

Abrupt warming across the West beginning in the 1980's brought on a marked increase in springtime temperatures, an earlier onset of spring by 8 to 10 days, a rise in the elevation at which it rains rather than snows, a decrease in snowpack, earlier snowmelt timing, a shift to an earlier pulse of snowmelt-fed discharge across the West, and an increase in the frequency of large fires (Cayan et al., 2001; Stewart et al., 2005, Mote et al., 2004; Knowles et al., 2006; Westerling et al., 2007; for a summary of some of these trends, see http://www.fs.fed.us/psw/cirmount/publications/pdf/new_terrain.pdf). Warming may already be driving lower annual streamflows in the Upper Colorado River Basin (Hoerling and Eisheid, 2005). Hotter and longer growing seasons also may already be exacerbating the effects of drought in the West, producing broadscale dieoffs of pinyon, ponderosa, and other species (Breshears et al., 2005)

In the deserts, warm season temperatures rose gradually over the past 3 or 4 decades, while winter and spring minimum temperatures rose sharply, again in the mid-1980's. For the Sonoran Desert, Weiss and Overpeck (2005) show lengthening of the freeze-free season and increased minimum temperatures per winter year; they suggest contraction of the overall boundary of the Sonoran Desert in the southeast and expansion northward, eastward and upward in elevation. Bowers (2007) used phenological models based on triggers and heat sums to predict annual date of spring bloom shrubs from the northern Sonoran Desert. The models showed advances of 2040 days in flowering time from 1894 to 2004, which were verified using herbarium specimens. This earlier bloom eventually could have substantial impacts on plant and animal communities in the Sonoran Desert, especially on migratory hummingbirds and population dynamics of shrubs. The abrupt warming beginning in the 1980's may also explain exponential spread of buffelgrass (*Pennisetum ciliare*) in the Sonoran Desert, which will continue to spread northward and upward with progressive warming. Without mitigation, buffelgrass invasion will surely convert much of the Sonoran Desert from fireproof desert to flammable grassland, perhaps in less than a decade.

The latest climate predictions for the Southwest in the 21st century come from intermodel comparisons for the recent Intergovernmental Panel on Climate Change (IPCC) AR4 assessment (IPCC 2007; http://www.ipcc.ch). The models used the A1B scenario, which assumes a future world of rapid economic growth, global population growth that peaks at 9 billion by 2050 and declines subsequently, and advancements in energy technology and policy. This conservative scenario would more than double of pre-industrial atmospheric levels by the end of the 21st century. The averaged output of 18 general circulation models for the Southwest indicates ~3°C warming by the end of the 21st century, with slightly more warming in summer than winter and most of the warming accomplished between 2030-2060. Simulations from the 18 general circulation models generally agree that the subtropics (i.e., the Southwest) will become drier while the high latitudes become wetter throughout the 21st century (Seager et al., 2007). This is due to the fact that global temperature increases atmospheric humidity, which in turn causes increased moisture divergence and northward expansion of the poleward edge of the Hadley Cell and mid-latitude westerlies. For the Southwest, Seager et al. (2007) suggest that by the end of the 21st century the mean climatology for the Southwest could resemble average conditions during the 1950's drought.

Questions about Ecological Responses to Climate Variability and Change

Based on the above discussion, I pose the following research questions about ecological responses to climate variability and change for consideration by DOD Legacy Resource Management, SERDP and ESTCP Program:

1. *What are the time-space domains of large-scale ecological variance (and synchrony), including disturbances and succession, and how do they interact with the spatiotemporal scales at which climate varies and changes?* How do the spatial and temporal scales of climate variability interact with phenology, plant and animal growth, disturbance regimes, population dynamics, community dynamics, and other ecosystem processes?

Knowledge about the spatiotemporal scales of this interaction is needed to inform strategies for forecasting, detecting, and adapting to ecological responses to climate variability and change.

2. *To what degree does climate variability synchronize ecological phenomena and at what temporal and spatial scales?* Identification of scales over which ecological patterns and processes are synchronous is required to minimize investigative effort in the field, maximize the generality of research results, and enhance the predictability of ecological responses to climate. What kinds of observational data and networks do we need to identify and understand ecological synchrony in the West? Once understood, what is the predictive value of this ecological synchrony? How will future climate change and variability affect ecological synchrony across populations, communities and ecosystems, and how might we manage for it? How will ecosystems shaped by ecological synchrony at a particular timescale of climate variability react to longer-term climatic change? What role will synchrony play in propagating ecological responses to climate change through adjacent regions?

3. *How will the secular warming trend interact with oscillatory modes of the large-scale climate system to affect regional climate, disturbance regimes, and plant and animal population dynamics in the West?* How will temperature increases and longer growing seasons interact with precipitation variability to affect the timing, frequency, intensity and areal extent of disturbances and surges in recruitment/mortality? How will earlier, longer and hotter growing seasons interact with precipitation variability timing and pace of invasions?

4. *Can we use climatic information to forecast disturbances, or predict their changing probabilities and trends across regions?* At what leads and with what uncertainties? How do antecedent conditions affect the climate-disturbance relationship? What climate precursors, thresholds and triggers produce extreme disturbances?

5. *How will climate variability and change determine the points in space and time at which one or more of the primary ecological processes responsible for maintaining the state of the ecosystem degrade beyond the point of self-repair- i.e., the ecological threshold?*

6. *How will weather, climate variability and climate change affect fire risk and behavior in newly-flammable ecoystems of the Sonoran and Mojave Desert?* We need to adapt or develop fire risk and fire spread models in desertscrub recently invaded by flammable grasses such as red brome and buffelgrass.

My oral presentation and white paper relied on the following sources:

Biondi, F., Kozubowski, T. J., and Panorska, A. K. 2005. A new model for quantifying climatic episodes. International Journal of Climatology 25, 1253-1264.

Bowers, J. E., 2005. El Niño and displays of spring-flowering annuals in the Mojave and Sonoran deserts. *Journal of the Torrey Botanical Society* 132:38-49.

Bowers, J.E., 2007. Has climatic warming altered spring flowering date of Sonoran Desert shrubs. *Southwestern Naturalist* 52, 347-355.

Breshears, D. D., N. S. Cobb, P. M. Rich, K. P. Price, C. D. Allen, R. G. Balice, W. H. Romme, J. H. Kastens, M. L. Floyd, J. Belnap, J. J. Anderson, O. B. Myers, and C. W. Meyer. 2005. *Proceedings of the National Academy of Sciences USA.* 102,15144-15148.

Cayan, D.R., Dettinger, M.D., Diaz, H.F., Graham, N.E. 1998. Decadal variability of precipitation over western North America. Journal of Climate 11, 3148-3166.

Cayan, D.R., Kammerdiener, S.A., Dettinger, M.D., Caprio, J.M., and Peterson, D.H., 2001, Changes in the onset of spring in the western United States: Bulletin of the American Meteorological Society, v. 82, p. 399-415

Cook, E.R., Woodhouse, C.A., Eakin, C. M., Meko, D.M. and Stahle, D.W. 2004. Long-term aridity changes in the western United States. *Science* 306, 1015-1018.

Cook, E.R., R. Seager, M.A. Cane and D.W. Stahle, 2007: North American Drought: Reconstructions, Causes, and Consequences, Earth Science Reviews 1-2, 93-134.

Dong, B., Sutton, R.T., and Scaife, A.A. 2006. Multidecadal modulation of El Nino-Southern Oscillation (ENSO) variance by Atlantic Ocean sea surface temperatures. *Geophysical Research Letters* 33, L8705, doi:10.1029/2006GL025766.

Cook, E.R., R. Seager, M.A. Cane and D.W. Stahle, 2007: North American Drought: Reconstructions, Causes, and Consequences, *Earth Science Reviews* 1-2, 93-134.

Enfield, D. B. and Cid-Serrano, L. 2005. Projecting the risk of future climate shifts. *International Journal of Climatology* (In press).

Gray, S. T., S. T. Jackson, J. L. Betancourt, 2004 Tree-ring based reconstructions of interannual to decadal-scale precipitation variability for northeastern Utah since 1226 A.D. *Journal of the American Water Resources Association* 40, 947-960.

Gray, S. T., Fastie, C., Jackson, S. T., and Betancourt, J. L. 2004. Tree-ring based reconstruction of precipitation in the Bighorn Basin, Wyoming since A.D. 1260. *Journal of Climate* 17, 3855-3856.

Gray, S.T., Graumlich, L.J., Betancourt, J.L. and Pederson, G.T. 2004. A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D. Geophysical Research Letters 31, L12205, doi:10.1029/2004GL019932.

Gray, S.T., J.L. Betancourt, C.L., Fastie, and S.T. Jackson, 2003. Patterns and Sources of Multidecadal Oscillations in Drought-Sensitive Tree-Ring Records from the Central and Southern Rocky Mountains. *Geophysical Research Letters* 30, 49-1.

Gray, S.T., Betancourt, J.L., Jackson, S.T., and Eddy, R., 2006, Role of multidecadal climate variability in a range extension of pinyon pine: Ecology, v. 87, p. 1,124-1,130.

Hidalgo, H.G., 2004. Climate Precursors of Multidecadal Drought Variability in the Western United States. *Water Resources Research* 40:W12504:10 p.

Hoerling, M.P., and Eischeid, J., 2006, Past peak water in the Southwest: Southwest Hydrology, v. 6, no. 1, p. 18–19, 35.

IPCC (Intergovernmental Panel on Climate Change), Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability Summary for Policymakers. April 6, 2007.

Kitzberger, T., P.M. Brown, E.K. Heyerdahl, T.W. Swetnam & T.T. Veblen. 2007. Contingent Pacific-Atlantic Ocean influence on multi-century wildfire synchrony over western North America.

Proceedings of the National Academy of Sciences 104, 543-548. Knight, J. R., C. K. Folland, and A. A. Scaife (2006), Climate impacts of the Atlantic Multidecadal Oscillation. Geophysical Research Letters 33, L17706, doi:10.1029/2006GL026242.

Knowles, N., Dettinger, M.D., and Cayan, D.R., 2006, Trends in snowfall versus rainfall in the western United States: Journal of Climate, v. 18, p. 4,545-4,559

Lu, J., G. A. Vecchi, and T. Reichler, 2007: Expansion of the Hadley cell under global warming. Geophysical Research Letters, 34, L06805, doi:10.1029/2006GL028443.

McCabe, G.J., Palecki, M.A., 2006. Multidecadal climate variability of global lands and oceans. *International Journal of Climatology* 26, 849-865.

McCabe, G. J., Palecki, M. A., and Betancourt, J. L. 2004. Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States. *Proceedings of the National Academy of Sciences* 101, 4136-4141.

McCabe, G., Betancourt, J.L., Hidalgo, H.G. 2007, Associations of decadal to multidecadal sea-surface temperature variability with Upper Colorado River flow: Journal of the American Water Resources Association, v. 43, no. 1, p. 183–192. doi:10.1111/j.17521688.2007.00015.x

McCabe, G.J., Betancourt, J.L., Gray, S.T., Palecky, M. A., Hidalgo, H.G., in press,Associations of multi-decadal sea-surface temperature variability with U.S. drought: *Quaternary International.*

Mote, P.W., A.F. Hamlet, M.P. Clark, and D.P. Lettenmaier, 2005: Declining mountain snowpack in western North America, *Bull. of the Amer. Meteorol.Soc.,*86, 39–49.

Schubert, S. D., Suarez, M.J., Pegion, P.J., Koster, R.D., Bacmeister, J.T. 2004. On the Cause of the 1930s Dust Bowl. *Science*, 303, 1855-1859.

Sheppard, P.R., A.C. Comrie, G.D. Packin, K. Angersbach, and M.K.. Hughes, 2002. The Climate of the Southwest. Climate Research. 21:219-238.

Seager, R., Kushnir, Y., Herweijer, C., Naik, N. and Velez, J. 2005: Modeling of tropical forcing of persistent droughts and pluvials over western North America: 1856-2000. *Journal of Climate* J. Climate 18:4068-4091.

Seager, R., Ting, M.F., Held, I.M., Kushnir, Y., Lu, J., Vecchi, G., Huang, H.-P., Harnik, N., Leetmaa, A., Lau, N.-C., Li, C., Velez, J., Naik, N., 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science, DOI:10.1126/science.1139601.

Siebold, J.S., Veblen, T.T., 2006. Relationships of subalpine forest fires in the Colorado Front Range with interannual and multidecadal-scale variation. Journal of Biogeography 33, 833-842.

Stewart, I., Cayan, D., and Dettinger, M.D., 2005, Changes towards earlier streamflow timing across western North America: Journal of Climate, v. 18, p. 1,136-1,155

Sutton, R. T., Hodson, D. L. R. 2005. Atlantic Ocean Forcing of North American and European Summer Climate. *Science* 309, 115-118.

Sutton, R.T., Hodson, D.L.R., 2007. Climate response to basin-scale warming and cooling of the North Atlantic Ocean. Journal of Climate 20, 891-907.

Swetnam, T.W. and Betancourt, J.L. 1998. Mesoscale disturbance and ecological response to decadal-scale climate variability in the American Southwest. *Journal of Climate* 11: 3128-3147.

Webb, R.H. and Betancourt, J.L., 1992, Climatic variability and flood frequency of the Santa Cruz River, Pima County, Arizona: *U.S. Geological Survey Water-Supply Paper* 2379.

Weiss, J.L. and J.T. Overpeck. 2005. Is the Sonoran Desert losing its cool? *Global Change Biology* 11: 2065-2077.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, T.W. Swetnam 2006: "Warming and Earlier Spring Increases Western U.S. Forest Wildfire Activity" *Science*, 313: 940-943. DOI:10.1126/science.1128834

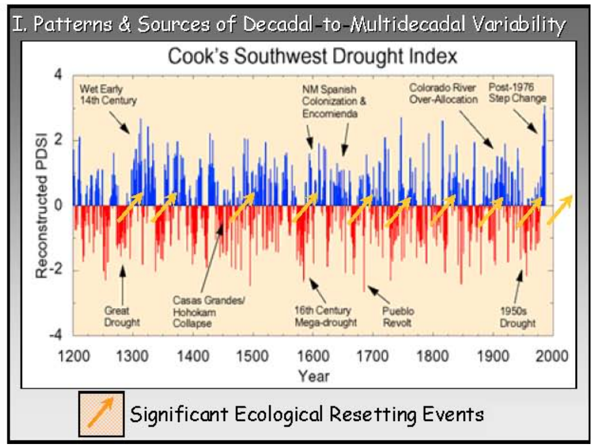
Woodhouse, C.A., Gray, S.T., and Meko, D.M., 2006, Updated streamflow reconstructions for the upper Colorado River basin: *Water Resources Research*, v. 42, doi:10.1029/2005WR004455.

Climate Variability & Change in the Southwest

Southwest Region
TER-S Workshop
October 22, 2007

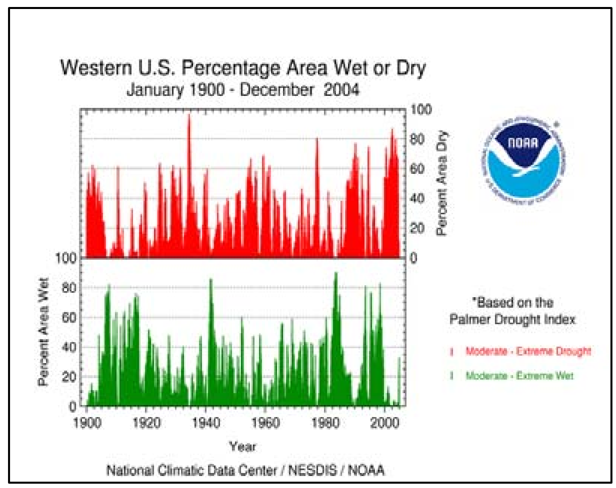
Julio Betancourt
U.S. Geological Survey
& Univ. of Arizona
jlbetanc@usgs.gov

Personal: http://wwwpaztcn.wr.usgs.gov/julio_cv.html
Desert Laboratory: http://wwwpaztcn.wr.usgs.gov/
USA-National Phenology Network: http://www.usanpn.org
S AZ Buffelgrass Effort: http://www.buffelgrass.org

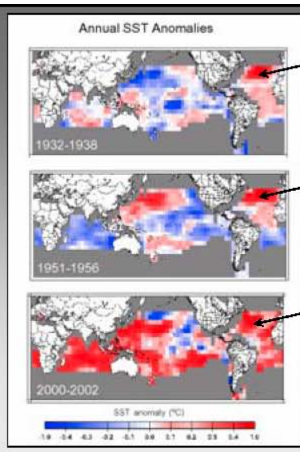


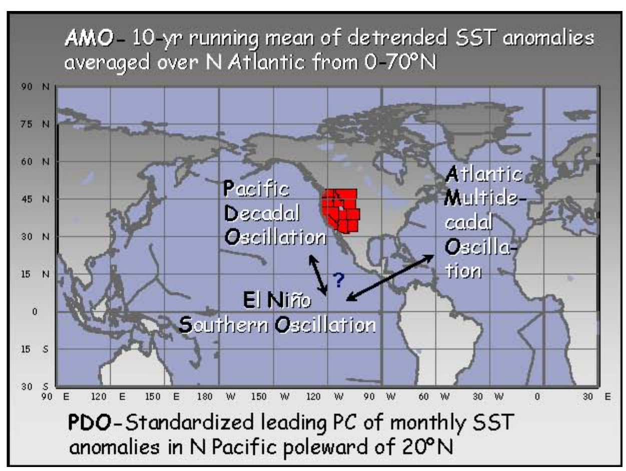
Understanding D2M variability: What's at stake?

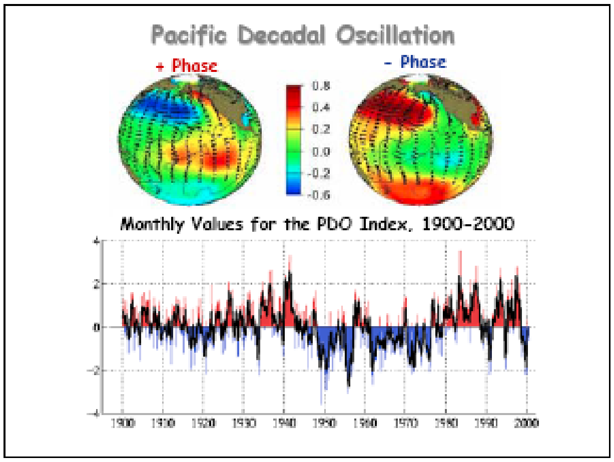
- Important for discriminating anthropogenic vs natural
- Key for understanding climatic impacts on natural systems (ecological legacies, long-term population dynamics, biological vs. climatic persistence)
- Implications for agricultural yield, water resources, river navigation, public health, conservation, hazards and risk management
- Potential predictability over multi-year timescales
- We haven't yet taken full stock of and adapted to natural D2M variability
  - how will anthropogenic forcing affect D2M?
  - how will D2M affect adaptation to climate change?

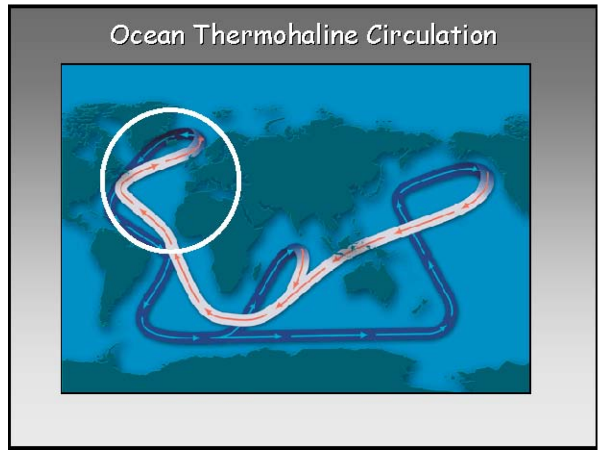


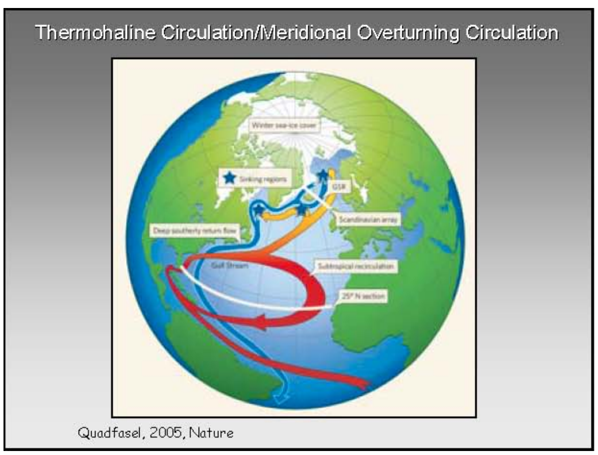
Global SST's and Drought Variability

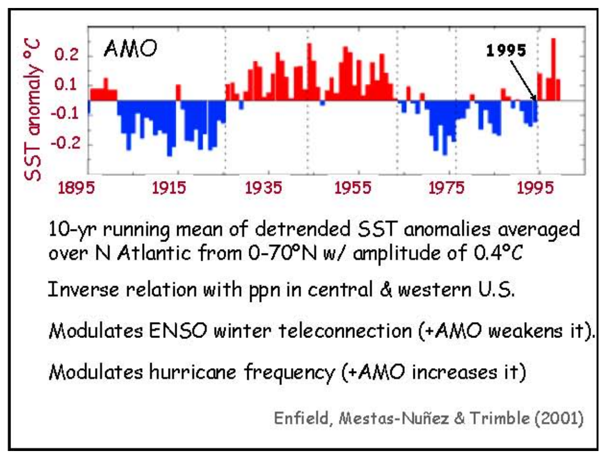


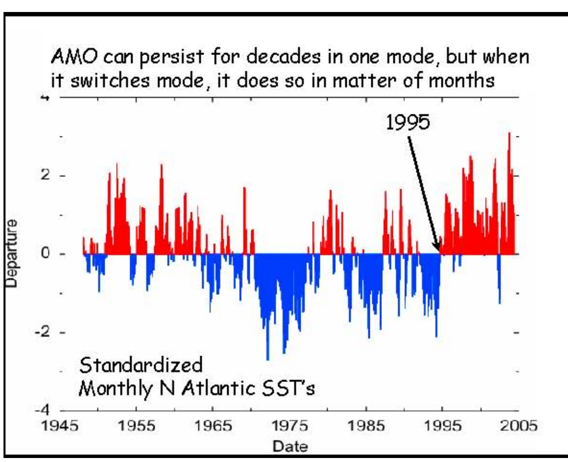


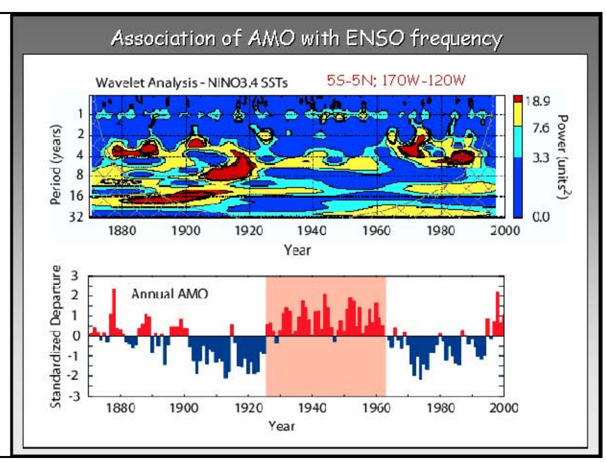

Pacific Decadal Oscillation
+ Phase
- Phase
0.8
0.4
0.2
0.0
-0.2
-0.6
Monthly Values for the PDO Index, 1900-2000
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000

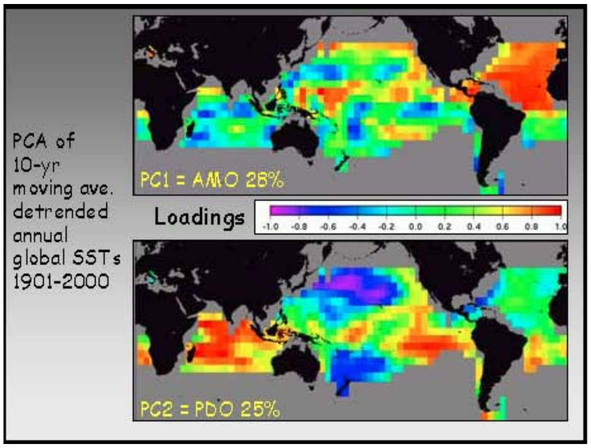

Ocean Thermohaline Circulation

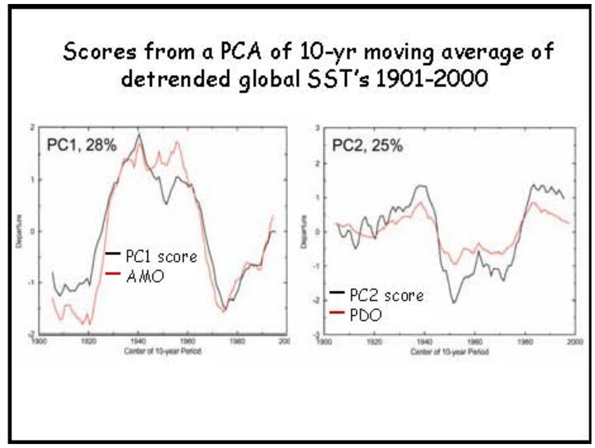

Thermohaline Circulation/Meridional Overturning Circulation
Quadfasel, 2005, Nature

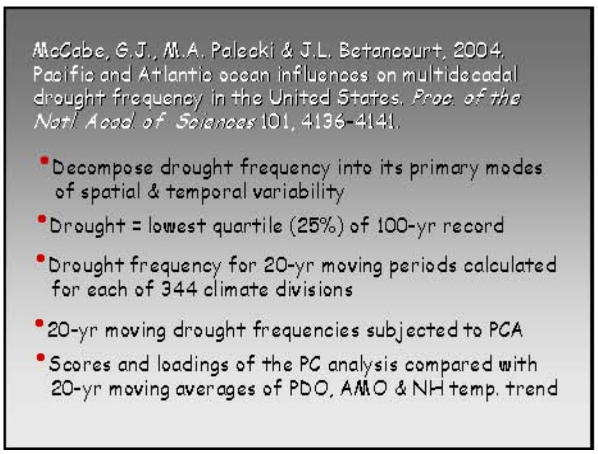

AMO
1995
SST anomaly °C
0.2
0.1
-0.1
-0.2
1895 1915 1935 1955 1975 1995
10-yr running mean of detrended SST anomalies averaged over N Atlantic from 0-70°N w/ amplitude of 0.4°C
Inverse relation with ppn in central & western U.S.
Modulates ENSO winter teleconnection (+AMO weakens it).
Modulates hurricane frequency (+AMO increases it)
Enfield, Mestas-Nuñez & Trimble (2001)

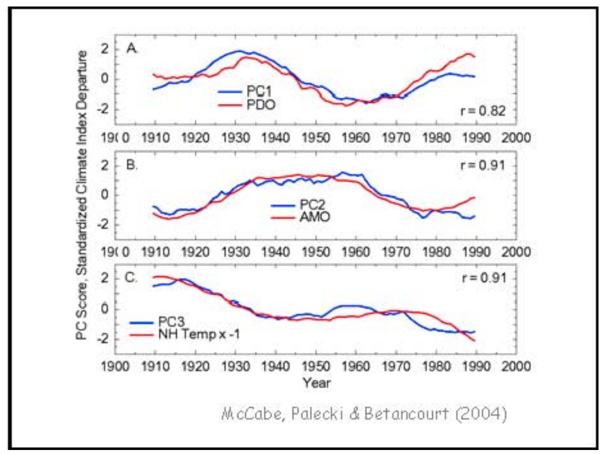

AMO can persist for decades in one mode, but when it switches mode, it does so in matter of months
1995
Departure
Standardized
Monthly N Atlantic SST's
1945 1955 1965 1975 1985 1995 2005
Date

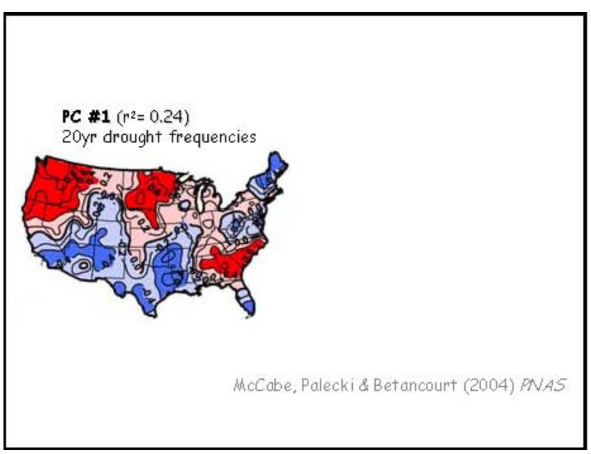

Association of AMO with ENSO frequency
Wavelet Analysis - NINO3.4 SSTs
5S-5N; 170W-120W
Period (years)
Power (units²)
Year
Annual AMO
Standardized Departure
Year

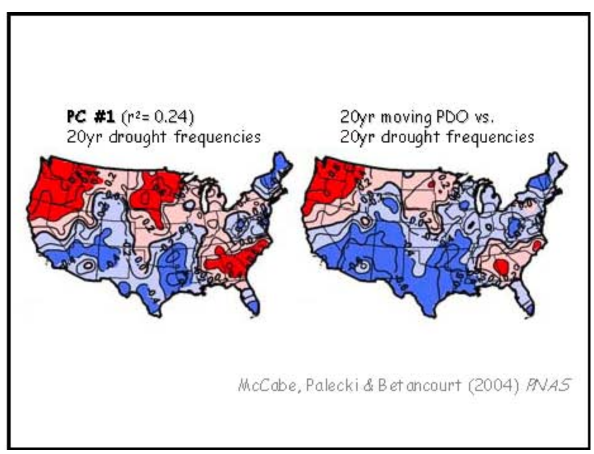

PCA of
10-yr
moving ave.
detrended
annual
global SSTs
1901-2000
PC1 = AMO 28%
Loadings
-1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0
PC2 = PDO 25%

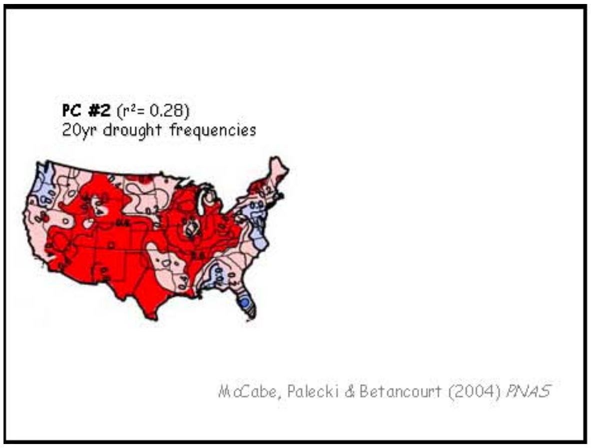

Scores from a PCA of 10-yr moving average of detrended global SST's 1901-2000
PC1, 28%
PC1 score
AMO
PC2, 25%
PC2 score
PDO
Center of 10-year Period

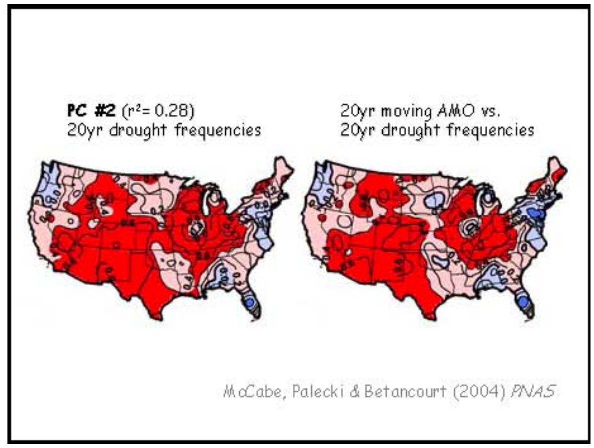

McCabe, G.J., M.A. Palecki & J.L. Betancourt, 2004. Pacific and Atlantic ocean influences on multidecadal drought frequency in the United States. Proc. of the Natl. Acad. of Sciences 101, 4136-4141.
Decompose drought frequency into its primary modes of spatial & temporal variability
Drought = lowest quartile (25%) of 100-yr record
Drought frequency for 20-yr moving periods calculated for each of 344 climate divisions
20-yr moving drought frequencies subjected to PCA
Scores and loadings of the PC analysis compared with 20-yr moving averages of PDO, AMO & NH temp. trend

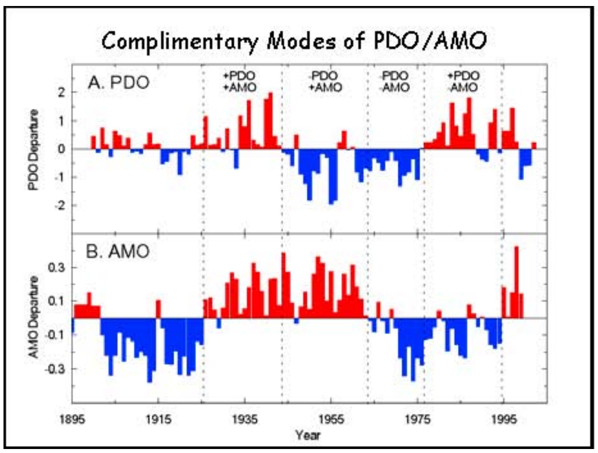

PC Score, Standardized Climate Index Departure
A.
PC1
PDO
r = 0.82
B.
r = 0.91
PC2
AMO
C.
r = 0.91
PC3
NH Temp x -1
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
Year
McCabe, Palecki & Betancourt (2004)

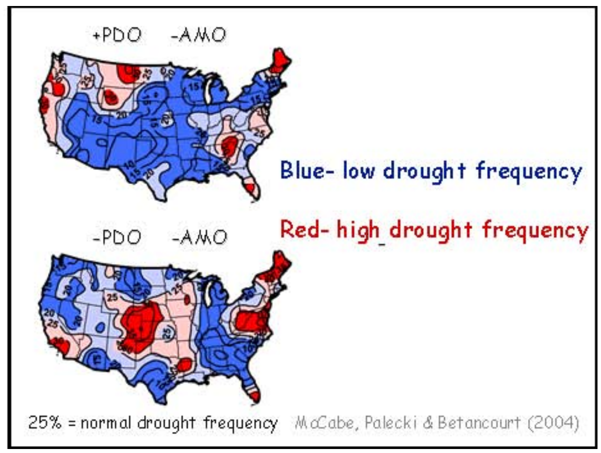

PC #1 (r^2= 0.24)
20yr drought frequencies
McCabe, Palecki & Betancourt (2004) PNAS

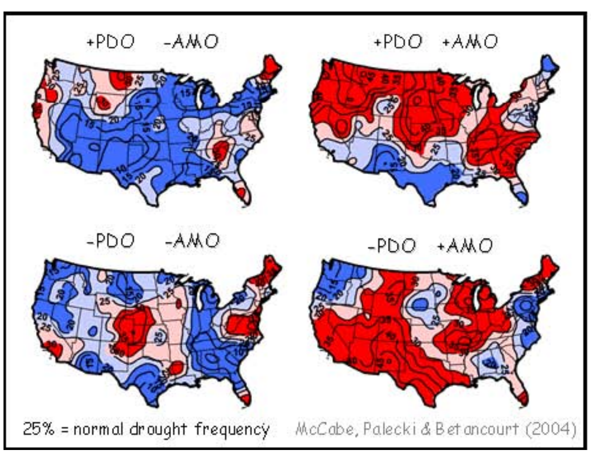

PC #1 (r^2= 0.24)
20yr drought frequencies
20yr moving PDO vs.
20yr drought frequencies
McCabe, Palecki & Betancourt (2004) PNAS

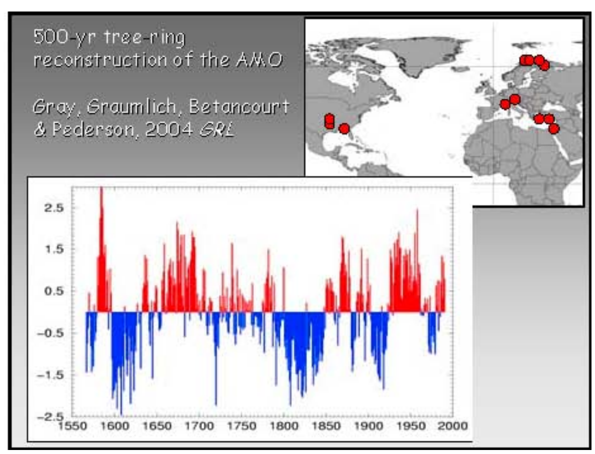

PC #2 (r^2= 0.28)
20yr drought frequencies
McCabe, Palecki & Betancourt (2004) PNAS

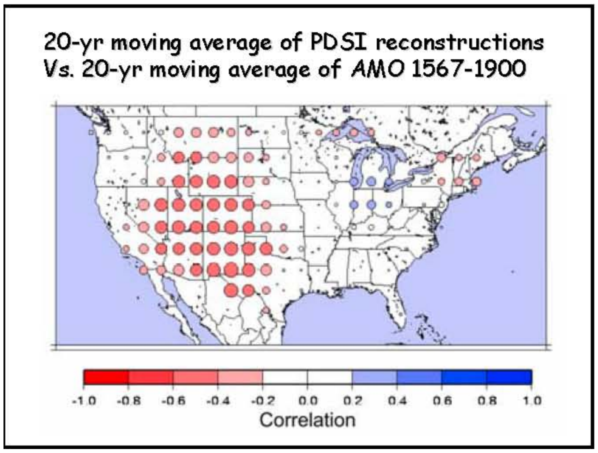

PC #2 (r^2= 0.28)
20yr drought frequencies
20yr moving AMO vs.
20yr drought frequencies
McCabe, Palecki & Betancourt (2004) PNAS

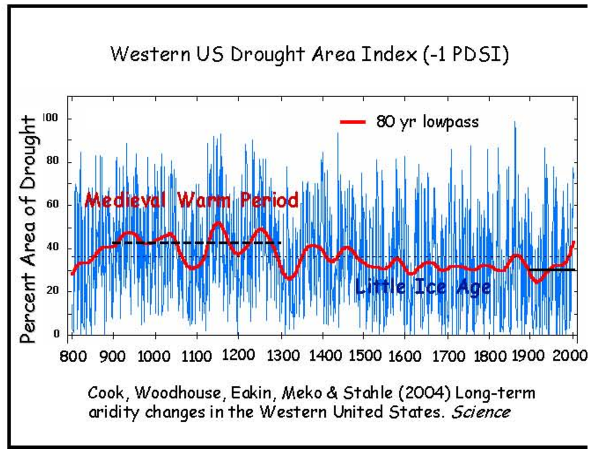

Complimentary Modes of PDO/AMO
A. PDO
+PDO +AMO
-PDO +AMO
-PDO -AMO
+PDO -AMO
PDO Departure
B. AMO
AMO Departure
Year

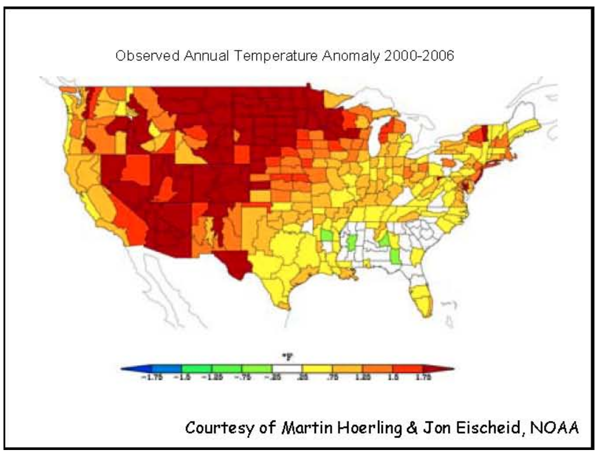

+PDO -AMO
-PDO -AMO
Blue- low drought frequency
Red- high drought frequency
25% = normal drought frequency
McCabe, Palecki & Betancourt (2004)

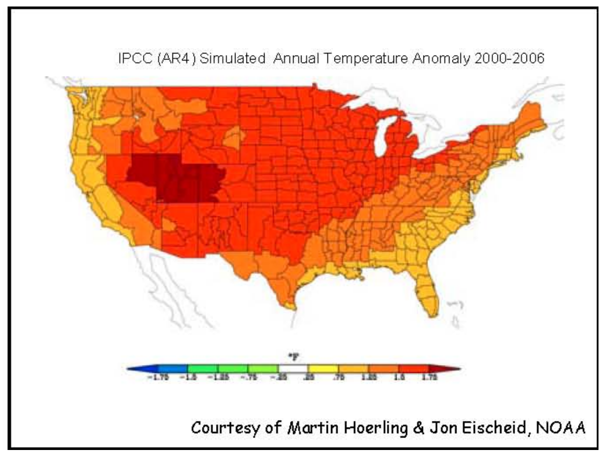

+PDO -AMO
+PDO +AMO
-PDO -AMO
-PDO +AMO
25% = normal drought frequency
McCabe, Palecki & Betancourt (2004)

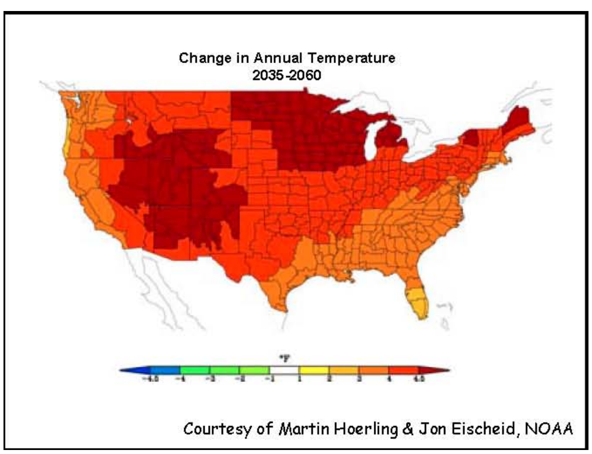

500-yr tree-ring reconstruction of the AMO
Gray, Graumlich, Betancourt & Pederson, 2004 GRL

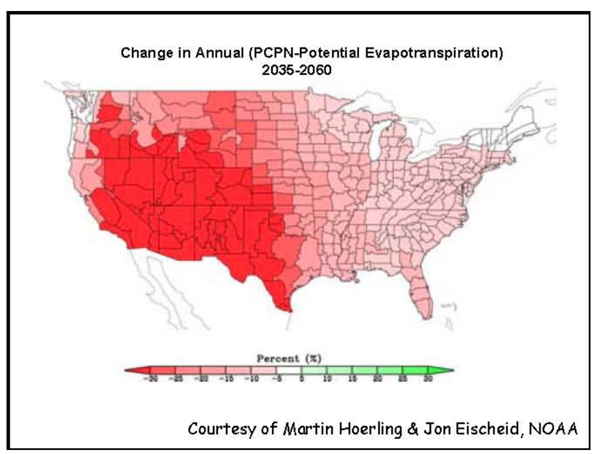

20-yr moving average of PDSI reconstructions
Vs. 20-yr moving average of AMO 1567-1900
-1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0
Correlation

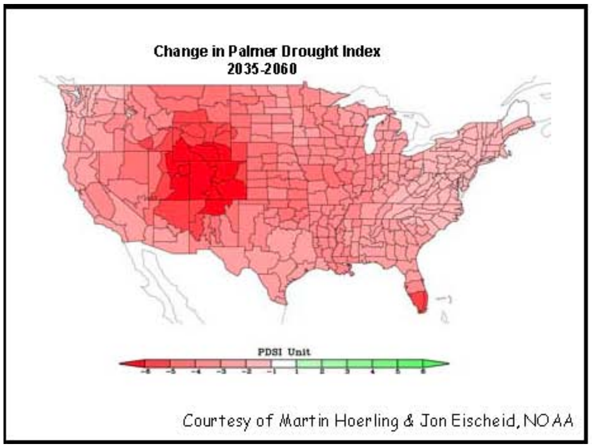

Western US Drought Area Index (-1 PDSI)
80 yr lowpass
Medieval Warm Period
Little Ice Age
Percent Area of Drought
0 20 40 60 80 100
800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
Cook, Woodhouse, Eakin, Meko & Stahle (2004) Long-term aridity changes in the Western United States. Science

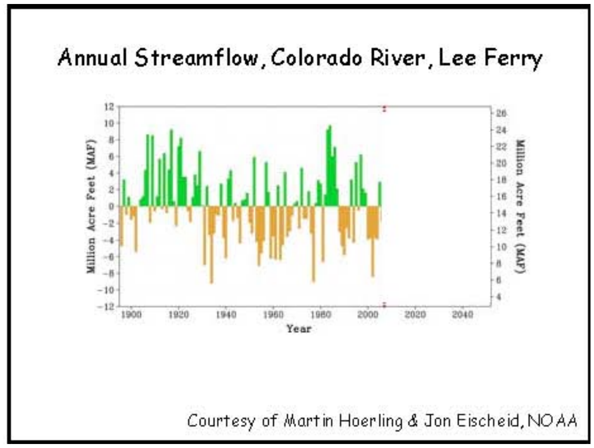

Observed Annual Temperature Anomaly 2000-2006
°F
Courtesy of Martin Hoerling & Jon Eischeid, NOAA

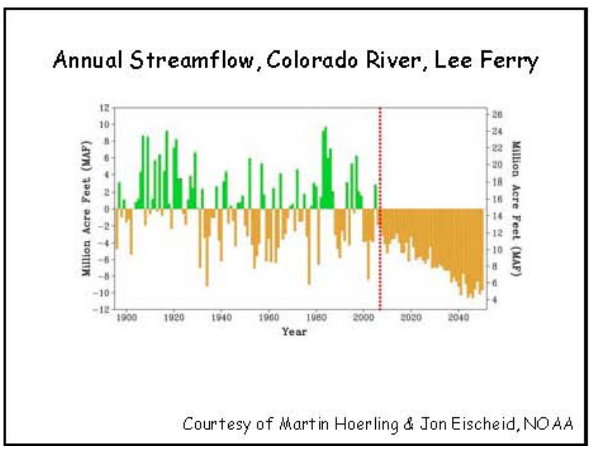

IPCC (AR4) Simulated Annual Temperature Anomaly 2000-2006
°F
Courtesy of Martin Hoerling & Jon Eischeid, NOAA

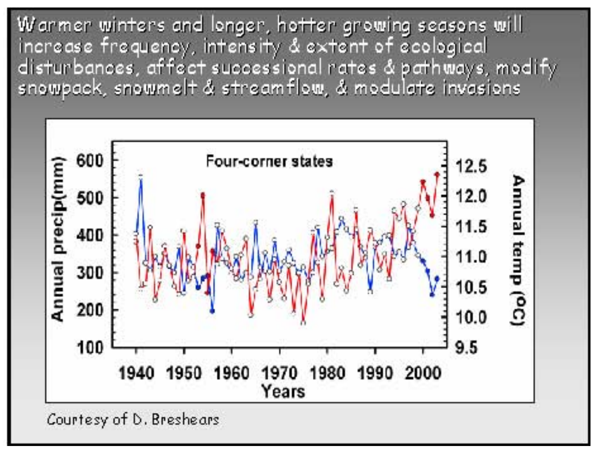

Change in Annual Temperature
2035-2060
°F
Courtesy of Martin Hoerling & Jon Eischeid, NOAA

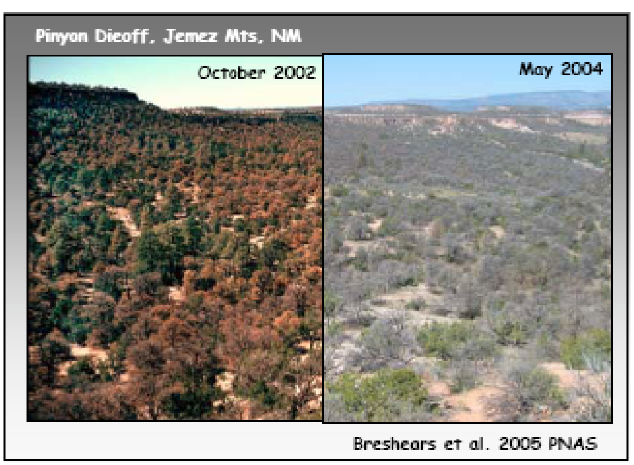

Change in Annual (PCPN-Potential Evapotranspiration)
2035-2060
Percent (%)
Courtesy of Martin Hoerling & Jon Eischeid, NOAA

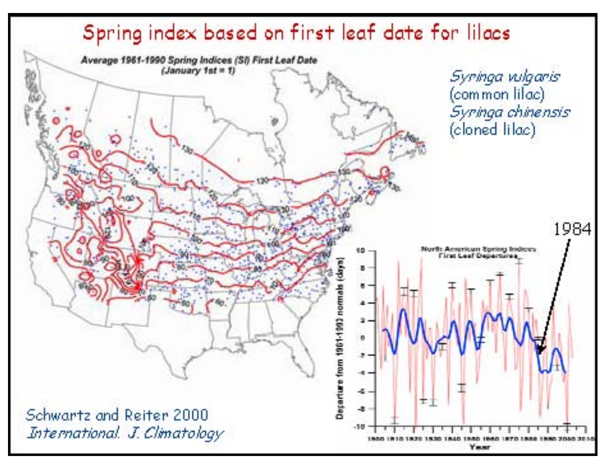

Change in Palmer Drought Index
2035-2060
PDSI Unit
Courtesy of Martin Hoerling & Jon Eischeid, NOAA

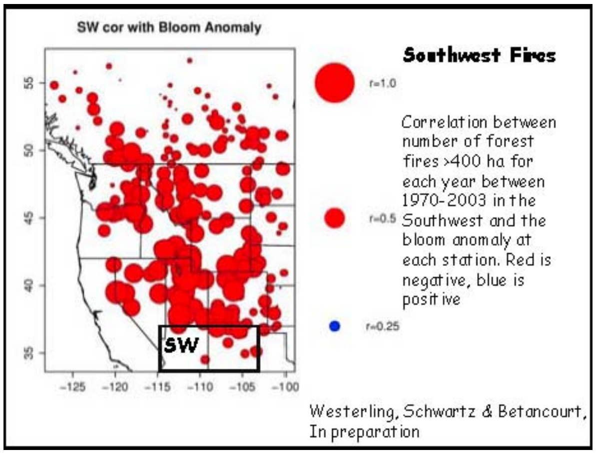

Annual Streamflow, Colorado River, Lee Ferry
Million Acre Feet (MAF)
Year
Million Acre Feet (MAF)
Courtesy of Martin Hoerling & Jon Eischeid, NOAA

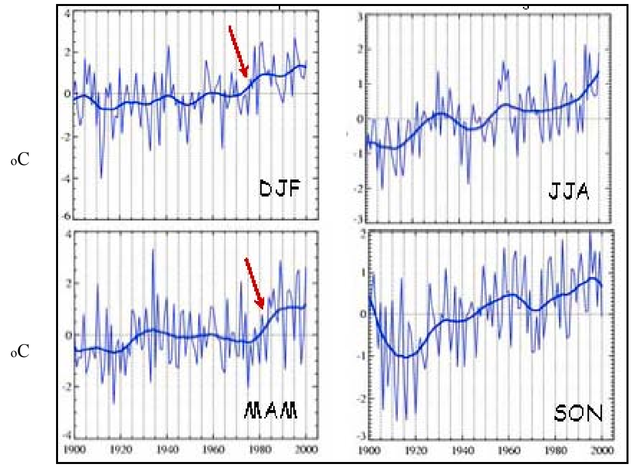

Annual Streamflow, Colorado River, Lee Ferry
Million Acre Feet (MAF)
Year
Million Acre Feet (MAF)
Courtesy of Martin Hoerling & Jon Eischeid, NOAA

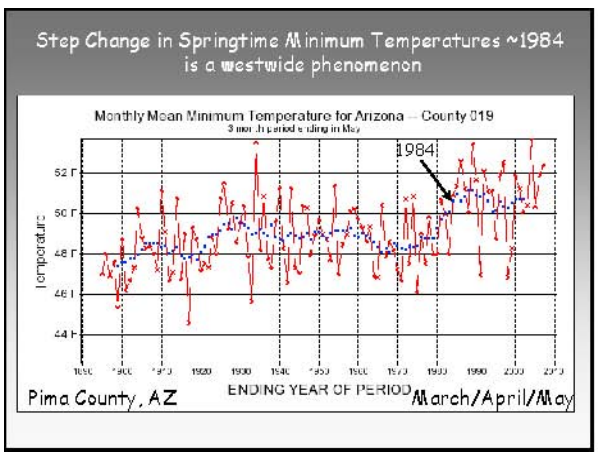

Warmer winters and longer, hotter growing seasons will increase frequency, intensity & extent of ecological disturbances, affect successional rates & pathways, modify snowpack, snowmelt & streamflow, & modulate invasions
Four-corner states
Annual precip(mm)
Annual temp (ºC)
Years
Courtesy of D. Breshears

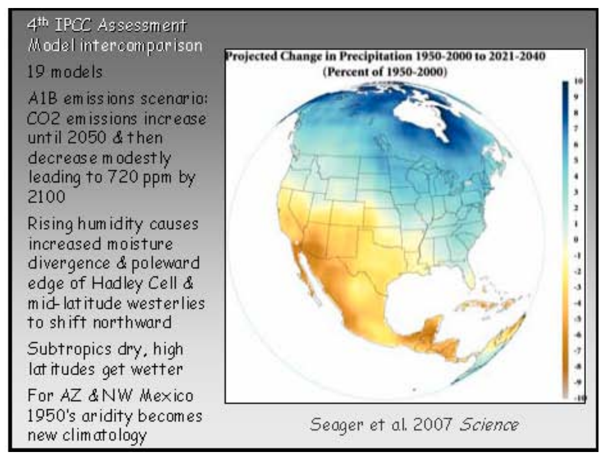

Pinyon Dieoff, Jemez Mts, NM
October 2002
May 2004
Breshears et al. 2005 PNAS

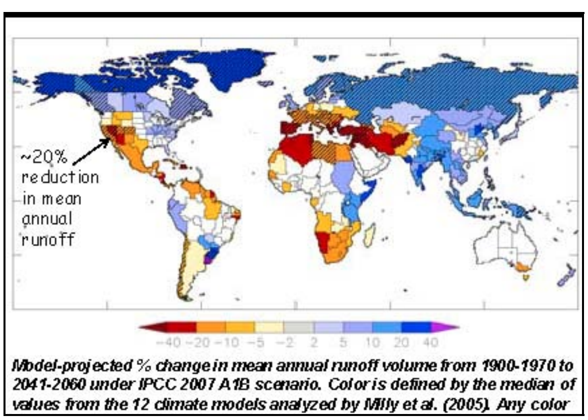

Spring index based on first leaf date for lilacs
Average 1961-1990 Spring Indices (SI) First Leaf Date
(January 1st = 1)
Syringa vulgaris
(common lilac)
Syringa chinensis
(cloned lilac)
1984
North American Spring Indices
First Leaf Departures
Year
Schwartz and Reiter 2000
International J. Climatology

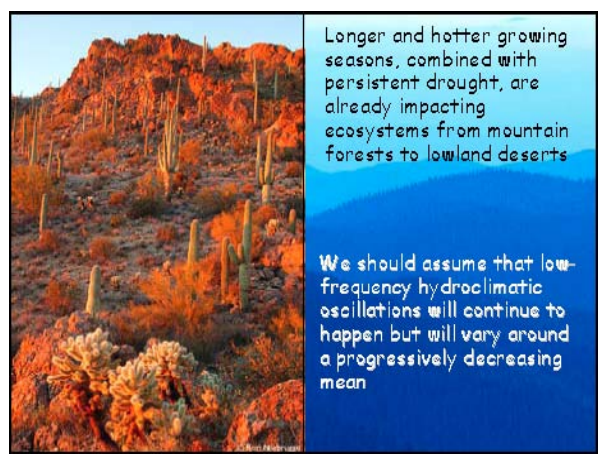

SW cor with Bloom Anomaly
Southwest Fires
r=1.0
r=0.5
r=0.25
Correlation between number of forest fires >400 ha for each year between 1970-2003 in the Southwest and the bloom anomaly at each station. Red is negative, blue is positive
SW
Westerling, Schwartz & Betancourt, In preparation

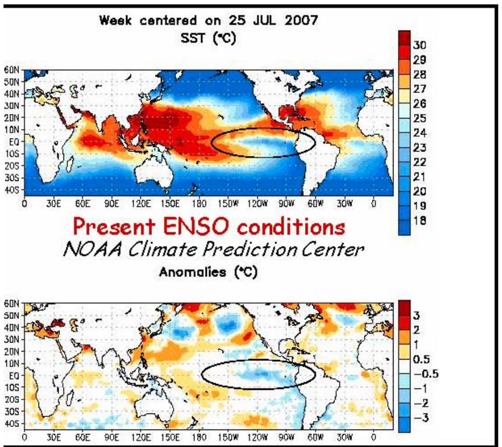

oC
oC
DJF
JJA
MAM
SON

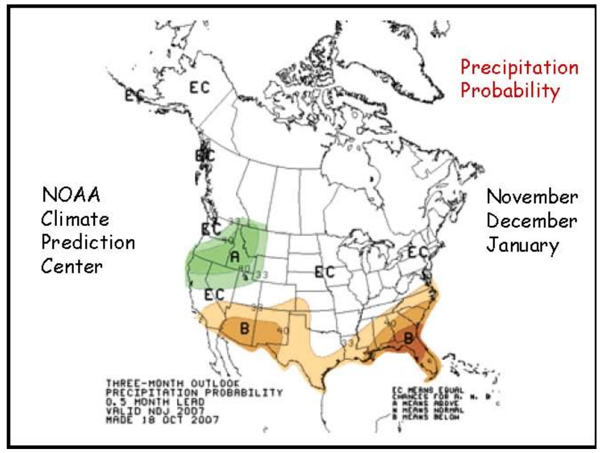

Step Change in Springtime Minimum Temperatures ~1984 is a westwide phenomenon
Monthly Mean Minimum Temperature for Arizona -- County 019
Temperature
ENDING YEAR OF PERIOD
Pima County, AZ
March/April/May

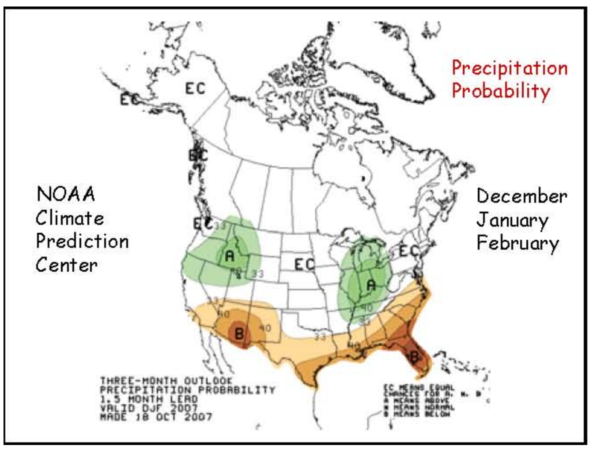

4th IPCC Assessment
Model intercomparison
19 models
A1B emissions scenario: CO2 emissions increase until 2050 & then decrease modestly leading to 720 ppm by 2100
Rising humidity causes increased moisture divergence & poleward edge of Hadley Cell & mid-latitude westerlies to shift northward
Subtropics dry, high latitudes get wetter
For AZ & NW Mexico 1950's aridity becomes new climatology
Projected Change in Precipitation 1950-2000 to 2021-2040
(Percent of 1950-2000)
Seager et al. 2007 Science

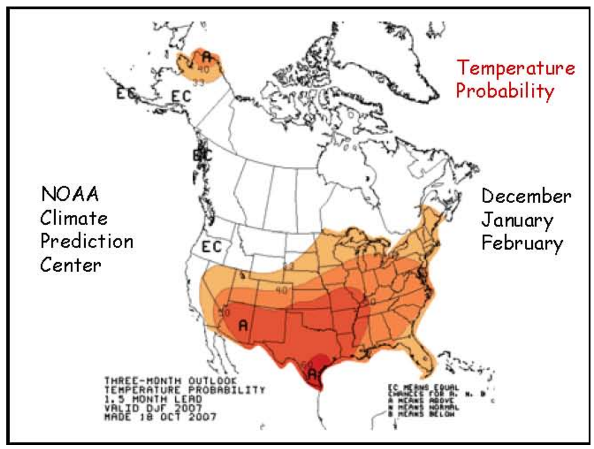

~20% reduction in mean annual runoff
-40 -20 -10 -5 -2 2 5 10 20 40
Model-projected % change in mean annual runoff volume from 1900-1970 to 2041-2060 under IPCC 2007 A1B scenario. Color is defined by the median of values from the 12 climate models analyzed by Milly et al. (2005). Any color


Longer and hotter growing seasons, combined with persistent drought, are already impacting ecosystems from mountain forests to lowland deserts
We should assume that low-frequency hydroclimatic oscillations will continue to happen but will vary around a progressively decreasing mean


Week centered on 25 JUL 2007
SST (°C)
Present ENSO conditions
NOAA Climate Prediction Center
Anomalies (°C)


Precipitation Probability
NOAA
Climate
Prediction
Center
November
December
January
THREE-MONTH OUTLOOK
PRECIPITATION PROBABILITY
0.5 MONTH LEAD
VALID NDJ 2007
MADE 18 OCT 2007


Precipitation Probability
NOAA
Climate
Prediction
Center
December
January
February
THREE-MONTH OUTLOOK
PRECIPITATION PROBABILITY
1.5 MONTH LEAD
VALID DJF 2007
MADE 18 OCT 2007


Temperature Probability
NOAA
Climate
Prediction
Center
December
January
February
THREE-MONTH OUTLOOK
TEMPERATURE PROBABILITY
1.5 MONTH LEAD
VALID DJF 2007
MADE 18 OCT 2007

Fire Regimes of the American Southwest

Matthew L. Brooks, Research Botanist United States Geological Survey, Western Ecological Research Center, Yosemite Field Station, El Portal California

Guy R. McPherson, Professor Natural Resources and Ecology & Evolutionary Biology, University of Arizona

Abstract

Fire regimes in many ecosystems of the southwestern United States have changed substantially coincident with Anglo settlement. In some desert shrublands, the incidence of fire has increased with increased fuelbed flammability following the invasion of non-native grasses. In most other areas, including desert grasslands, woodlands, and lower elevation forest, fire has become less prevalent due to fire suppression, removal of fine fuel by livestock, fragmentation of formerly continuous fuels by economic development, and other anthropogenic factors. Global climate change is contributing to warming and altered precipitation patterns in this region, and nonnative grasses continue to spread throughout the region. probable consequences include increased fire extent and intensity in most of the region's ecosystems.

Introduction

This white paper is organized around the major ecosystems of the southwestern United States. It is based on a comprehensive review of relevant literature, and it provides an overview of past, contemporary, and potential future fire regimes. When possible, it relies on studies from the southwest, but also incorporates information from similar ecosystems in other regions. This paper addresses the following ecosystems: spruce-fir forest, mixed-conifer forest, ponderosa pine forest, evergreen oak woodland, pinyon-juniper woodland, southwestern shrublands, and southwestern grassland. Savannas dominated by oak, juniper, and mesquite are described within the context of adjacent woodlands and grasslands. Consideration of fire in riparian systems is beyond the scope of this monograph, and is described elsewhere (2003, *Forest Ecology and Management* special issue, volume 178).

Spruce-Fir Forest

Spruce-fir forests correspond to the southwestern spruce-fir type of Kuchler's (1964) classification system. Spruce-fir forests are uncommon in the American Southwest, yet they have received considerable attention from the scientific community (e.g., Alexander 1974, Jones 1974, Dye and Moir 1977, Moir and Ludwig 1979, Alexander 1987, Stromberg and Patten 1991, Dyer and Moffett 1999, Fulé and others 2003a). This attentiveness to a relatively uncommon ecosystem probably results in part from the high biological diversity these systems contribute to the region. Spruce-fir forests are the highest-elevation ecosystems in the region occurring above 8,000 ft. As the pinnacle ecosystems in southwestern "sky islands," they harbor several rare taxa, including the federally endangered Mt. Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) and the federally threatened Mexican spotted owl (*Strix occidentalis lucida*). Because of the moisture and temperature relations associated with their topographic position, these forests also serve as a bellwether for regional climate change.

Common tree species include Engelmann spruce (*Picea engelmannii* Parry), subalpine fir [*Abies lasiocarpa* var. *lasiocarpa* (Hook.) Nutt.] and its southern variety, corkbark fir [*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.], and quaking aspen (*Populus tremuloides* Michx.). Scattered individuals or small stands of blue spruce (*Picea glauca* Engelm.) are occasionally found, especially in riparian areas. White fir [*Abies concolor* (Gord. & Glend.) Lindl.] and Douglas-fir [*Pseudotsuga menziesii* var. *glauca*

(Breissn.) Franco] commonly occur after stand-replacing events and may persist for several hundred years, especially on relatively dry sites. New Mexico locust (*Robinia neomexicana* Gray) frequently occurs as a small understory tree.

The typical fire regime before Anglo settlement included stand-replacing fires of relatively high intensity every few hundred years (Grissino-Mayer et al., 1995, Fulé et al., 2003a). Before Anglo settlement, these fires typically were ignited by lightning during late June and early July thunderstorms at the leading edge of the southwestern "monsoon." In the absence of fire suppression, these fires burn until they are doused by heavy monsoonal storms; during years of little summer precipitation, they may burn until the first snowfall.

Periodic fires may be required to retain spruce as a significant component of these forests. Shade-intolerant spruce trees often are replaced by subalpine fir or corkbark fir in the long-term absence of fire (Peet 1988). However, low adult mortality and long life-span of Engelmann spruce allow the species to persist for 500 years or more in the absence of fire (Shea 1985). Nonetheless, fire was a recurrent phenomenon, albeit at a temporal scale on the order of centuries, and presumably an integral component of forest dynamics in these systems before Anglo settlement (Stromberg and Patten 1991).

Given the long fire-return intervals that characterized these forests before Anglo settlement, it seems reasonable to assume that a century of fire suppression has had minimal impact on stand dynamics or structure. Thus, the contemporary fire regime probably is very similar to the pre-settlement regime. Prescribed fires have been attempted only rarely and at very small spatial extents in these forests. Considering the susceptibility of the dominant tree species to fires and the fuel and weather conditions associated with historical and contemporary fires, introducing prescribed fire into spruce-fir forests seems unwarranted.

Although the fire regime apparently has been largely unaffected by Anglo settlement, the impacts of contemporary fires probably will differ from those of pre-settlement fires. Specifically, regional warming and drying as a result of anthropogenic global warming probably affect tree recruitment patterns. Given the tendency for Engelmann spruce to establish slowly on relatively xeric sites, and the 80- to 250-year lag in establishment of corkbark fir, it is increasingly likely that stand-replacing fires will cause spruce-fir forests to be replaced by forests dominated by white fir or Douglas-fir. Although a warmer, drier climate has been gradually replacing a cooler, wetter climate since the advent of the Holocene some 11,000 years ago, the dramatic acceleration of this pattern during the last century portends rapid changes in stand structure of these high-elevation forests. Rapid warming and drying should elevate the likelihood of fire occurrence and intensity in these forests; this pattern already is evident in some North American coniferous forests (Wotton et al., 2003), and models indicate the pattern will soon spread to other such forests (Baker 2003; Flannigan et al., 2003; Miller 2003). Warming and drying further threaten these forests by elevating moisture stress, thereby weakening individual trees and predisposing them to attack by insects such as the native western spruce budworm (*Choristoneura occidentalis*), the native spruce beetle (*Dendroctonus rufipennis*), and several native and nonnative species of aphid (genera *Adelges*, *Cinara*, and *Pineus*). The resulting increase in dead trees threatens to exacerbate the increased probability of fire occurrence and spread produced more directly by anthropogenic warming and drying.

Mixed-Conifer Forest

Mixed-conifer forests are found at sites drier than spruce-fir forests and moister than those dominated by ponderosa pine (*Pinus ponderosa* var. *scopulorum* P. & C. Larson). This document combines the spruce-fir-Douglas-fir and pine-Douglas-fir types of Kuchler's (1964) classification into the general category of mixed-conifer forest. These forests are typically found at elevations between 6,500 feet and 9,000 feet.

Common tree species include Douglas-fir, southwestern white pine (*Pinus strobiformis* Engelm.), ponderosa pine, white fir, and quaking aspen, often in that order of abundance. New Mexico locust is also a common understory tree. Pinyon-juniper woodlands, which also may be classified as mixed-conifer forests, typically are found on drier sites than stands of ponderosa pine and are described in later sections.

Most mixed-conifer forests resulted from fire, and the relatively complex, mixed-intensity fire regimes that create and maintain these forests produce a rich mosaic of trees across the landscape. Before Anglo settlement, fire intensity varied considerably within a stand, such that some areas did not burn, others burned as low-intensity surface fires, and other patches burned as high-intensity crown fires. Lightning during summer, especially during late June and early July, ignited virtually all fires, some fires may have been lit by native Americans, although such ignitions are quite difficult to demonstrate conclusively (e.g., Seklecki et al., 1996). This mixed-severity regime is undoubtedly responsible for the presence of trees with varying fire tolerances, and for intra- and inter-stand diversity in species composition.

There is little question that fire was a recurrent phenomenon and presumably an integral component of forest dynamics in these systems before Anglo settlement. Dendrochronological analyses suggest mean surface-fire intervals of 3 to 20 years (Baisan and Swetnam 1990, 1995; Swetnam 1990; Grissino-Mayer et al., 1995; Danzer et al., 1996; Seklecki et al., 1996; Swetnam and Baisan 1996; Touchan et al., 1996; Fulé et al., 2002, 2003a, 2003b). Other analyses conclude the mean time between surface fires ranged from 30 to 200 years (Baker and Ehle 2001, 2003). Both sets of figures suggest that the surface-fire regime has been disrupted by anthropogenic activities, and indicate that surface fires should be reintroduced into these systems during the summer, when they occurred with more historic frequency.

The contemporary fire regime has been affected by the suppression of low-intensity surface fires throughout the 1900s. Fire spread has been further reduced by human-induced fragmentation. Occurrence of historically infrequent high-intensity crown fires has been reduced within landscapes and within stands. Decreased heterogeneity of fires within stands—specifically a reduction in patches that burn into the forest canopy—translates to more homogeneous stand conditions and further increases in fuel accumulation. The virtual absence of surface fires and the attendant reduction in the number of patches of trees that “crown out” has allowed large woody fuels to accumulate. Along with expected rapid warming and drying, these factors likely have elevated the likelihood of stand-replacing fires in these forests. Considering the high probability of increased warming and drying in the foreseeable future, we expect stand-replacing fires to increase.

Ponderosa Pine Forest

Ponderosa pine forests are found at sites drier than mixed-conifer forests and moister than pinyon-juniper woodlands, though the ecotone between these types is very broad in some mountain ranges. Ponderosa pine forests correspond to Kuchler’s (1964) Arizona pine forest, and are typically found at elevations between 6,000 feet and 7,000 feet.

The dominant tree species is ponderosa pine, and it varies in density from very open stands to dense thickets. This variation in stem density often is attributed to human-induced changes in fire regimes, with increased density attributed to the virtual absence of fires since the late 1880s (e.g., Brown 1982; Wright and Bailey 1982; Pollet and Omi 2002). Gambel oak (*Quercus gambelii* Nutt.) and New Mexico locust are common subordinates that may be locally dominant on relatively xeric or rocky sites. On relatively mesic sites, subordinate species include Douglas-fir, southwestern white pine, and quaking aspen.

The relatively continuous ponderosa pine forest stretching along the Mogollon Rim between northern Arizona and central New Mexico is reportedly the largest ponderosa pine forest in the world (Fulé et al.,

2001). It is the only major commercial forest in the American Southwest. These factors help explain the considerable attention paid to ponderosa pine forests in the region.

Probably no ecosystem is better studied, especially with respect to fire history and ecology, than these forests in this region. Despite this long history of study (or perhaps because of it), there is considerable debate about historical fire regimes. For many years, scientific consensus held that ponderosa pine forests were characterized by high-frequency, low-intensity surface fires. Within the last decade, considerable evidence points to the existence of infrequent, high-intensity crown fires (e.g., Shinneman and Baker 1997; Brown et al., 1999; Johnson et al., 2001; Ehle and Baker 2003). It now seems that most stands were characterized by a mixed regime, with a regime of frequent surface fires overlain by infrequent, stand-replacing fires. A holistic perspective that incorporates weather, climate, and site-specific attributes of stands can explain much of this variability.

Although fire occurrence and behavior are strongly dependent on weather conditions (Bessie and Johnson 1995, Shinneman and Baker 1997, Pierce et al., 2004), the density and cover of ponderosa pine may affect fire frequency, seasonality, and intensity. Historically, a positive feedback probably was maintained on many sites, with low stem density contributing to high-frequency, low-intensity fires during the early summer (coincident with the southwestern monsoon). This fire regime probably maintained relatively open, park-like stands of widely scattered pine trees throughout the American Southwest for many years, and perhaps for centuries at a time on some sites. Closed-canopy stands doubtless established on relatively mesic sites and during periods of above-average precipitation (e.g., Humphries and Bourgeron 2003). The "ladder fuels" in these stands could carry fire into tree canopies, where fire behavior is largely controlled by foliar moisture (Agee et al., 2002; Bilgili 2003). Thus, mixed fire regimes could have occurred on most sites currently dominated by ponderosa pine, and the transition from a regime dominated by high-frequency, low-intensity surface fires to one dominated by low-frequency, high-intensity crown fires could result from modest variations in precipitation over relatively short periods of time. For example, a decade-long period of above-average precipitation could engender rapid recruitment and growth of pine trees while also acting to reduce fire occurrence and spread. A subsequent decade-long period of below-average precipitation could lower fuel moisture, thereby triggering widespread stand-replacing fires. Individual fires tend to be highly variable in behavior, and heterogeneity in fuels, microclimate, and myriad other factors explain why even fires in very dry, closed-canopy forests rarely behave only as crown fires (Kafka et al., 2001). A large-scale, long-term perspective that incorporates spatial and climatic variability thus helps clarify a debate arising from apparently conflicting data.

Stand-replacing fires probably have become more common since livestock grazing and fire suppression largely eliminated low-intensity surface fires within the last century or so. However, stand-replacing fires likely were common during the "Medieval Climatic Anomaly" (MCA) of ca. 1,050 – 650 years ago (Pierce et al., 2004); and contemporary and likely near-future climatic patterns are similar to the MCA (Crowley 2000, Bradley et al., 2003).

Gambel oak, New Mexico locust, or both species typically dominate the post-fire overstory, often for several decades. When heavy rains follow stand-replacing fires, significant soil loss may occur, especially on sites with relatively steep slopes. On these sites, shrub thickets may persist for several centuries, even in the face of attempts to reintroduce ponderosa pine forests. The inherent productivity of these sites is compromised by the loss of soil, and efforts to reforest them are not successful.

Evergreen Oak Woodland

Evergreen oak woodlands (the "encinal" of Shreve 1915) occur primarily along the Mogollon Rim and in the mountains of southeastern Arizona and extreme southwestern New Mexico. These woodlands correspond roughly to the oak-juniper type of Kuchler's (1964) classification system, although Kuchler

does not acknowledge the extensive stands of oaks in which juniper trees are absent. These woodlands typically are found at elevations of 5,000 feet to 6,500 feet, above semi-desert grassland and below ponderosa pine forest (with which evergreen oak woodlands mix and co-mingle).

Dominant trees in Arizona woodlands include Emory oak (*Quercus emoryi* Torr.), Arizona white oak (*Q. arizonica* Sarg.), and south of the Gila River, Mexican blue oak (*Q. oblongifolia* Torr.). Emory oak and gray oak *(Q. grisea* Liebm.) are dominant in southeastern Arizona and southern New Mexico, and silverleaf oak *(Q. hypoleucoides* Camus) and netleaf oak (*Q. rugosa* Nee) dominate at relatively mesic high-elevation sites. Warm-season grasses dominate the understory throughout the region, particularly at the lower and drier end of this type as it grades into oak savanna and then semi-desert grassland.

Fire regimes in southwestern oak woodlands has been understudied relative to other systems in the region. This is partly due to the rarity of fire scars on the dominant tree species, and the stem age of the dominant species is neither easily nor reliably determined via dendrochronological techniques. Finally, stem age does not indicate age of establishment because many individuals of all southwestern species resprout when top-killed. Thus, fire history can not be inferred from stand structure (McPherson 1997, McPherson and Weltzin 2000).

Savannas at the lower and drier margin of oak woodlands probably burned every 10-20 years on average, similarly to adjacent grasslands. Variability doubtless was quite high, with fires occurring as frequently as every two years (Kaib et al., 1996). Interruption of frequent fires since Anglo settlement likely contributed to the development of stands with increased stem densities within the last century (e.g., McPherson et al., 1993), a trend that has been documented for other savannas throughout the world (Archer 1994, McPherson 1997). These low-intensity surface fires likely swept into the adjacent closed-canopy woodlands during some years.

It seems unlikely that closed-canopy woodlands, with their lack of herbaceous understory, would have supported surface fires at the high frequency found in adjacent savannas. However, these trees shed all their leaves each year a few months before the southwestern monsoon as new leaves expand to replace the leaves from the previous year. These leaves decompose slowly and they are well-dried between leaf senescence (ca. April) and the first thunderstorm (typically, early July). Thus, the abundant supply of leaves may have served as volatile fuel, especially in concert with fine woody fuels that accumulated over time. The few months of consistently hot, dry weather between leaf senescence and lightning activity may have created conditions amenable to high-intensity crown fires. Under this scenario, trees that survived the fire would resprout and seedlings would recruit from acorns into the bare spaces. Thus, these woodlands may have been characterized by periodic low-intensity surface fires and less frequent high-intensity crown fires. In the absence of fire-history data in these systems, this scenario remains only speculative.

Pinyon-Juniper Woodland

Pinyon-juniper woodlands occur mostly north of the Mogollon Rim in Arizona and New Mexico, and on into Utah. Pinyon and juniper trees dominate many relatively xeric sites north of the Mogollon Rim, where they correspond to the juniper-pinyon type of Kuchler's (1964) classification system. South and west of the Rim, this woodland is found in a band of vegetation between about 4,000 feet and 6,000 feet in the sky islands; here they comprise part of the oak-juniper type of Kuchler's (1964) classification system. In this area, they are the lowest elevation ecosystems in the southwestern United States dominated by conifers, and they typically occur just above desert shrublands in the Mojave and western Sonoran deserts, and above semi-desert grasslands in the eastern Sonoran and Chihuahuan deserts.

Common tree species include Rocky Mountain (synonymous with doubleleaf) pinyon (*Pinus edulis* Engelm.), singleleaf pinyon (*P. monophylla* Torr. & Frem.), Rocky Mountain juniper (*Juniperus. scopulorum* Sarg.), Utah juniper [*J. osteosperma* (Torr.) Little], and one-seed juniper [*J. monosperma* (Engel.) Sarg.] north of the Mogollon Rim and in the Mojave Desert. Mexican pinyon (*Pinus cembroides* Zucc.), one-seed juniper, and alligator juniper (*J. deppeana* Steud.) are characteristics species south of the Rim. Pinyon trees typically are restricted to the more mesic sites in these woodlands, and are therefore mostly absent from low-elevation sites where pinyon-juniper woodland contacts grassland. Rocky Mountain juniper is found on more mesic sites than the remaining juniper species. A well-developed shrub understory dominated by big sagebrush (*Artemisia tridentata* Nutt.) is often present beneath pinyons and junipers on the Colorado Plateau and in the higher mountain ranges of the Mojave Desert. Cool-season (C_3) grasses dominate the understory on the Colorado Plateau, giving way to warm-season (C_4) grasses south of the Mogollon Rim and east of the continental divide in New Mexico. These grasses are much less abundant in the pinyon-juniper woodlands of the Mojave Desert.

Before Anglo settlement, pinyon-juniper woodlands were characterized by a mixed fire regime. Low-intensity surface fires were carried by herbaceous fuels, primarily grasses, in relatively xeric juniper savannas. Stand-replacing fires of moderate intensities characterized more mesic sites, especially on the Colorado Plateau where shrubs were common in the understory. These fires typically were ignited by lightning during late June and early July thunderstorms at the leading edge of the southwestern "monsoon." The pre-Columbian fire regime of pinyon-juniper woodlands can be classified into three distinct types (Romme et al., 2003).

Before Anglo settlement the most xeric pinyon-juniper stands that abutted southwestern grasslands in Arizona and New Mexico burned every 5 to 20 years, with considerable variability around mean frequency. Time between fires depended strongly on post-fire recovery of grasses. Fires in these savannas were constrained by accumulation of herbs, such that they occurred most frequently on relatively productive sites (e.g., those with high precipitation and deep, well-drained soils) and less frequently on less-productive sites or during periods of below-average precipitation. Fires spread quickly, and burned until they were doused by monsoonal storms or encountered fuel breaks such as rivers and escarpments.

Various juniper species invaded these grassland and savanna sites during the last century, presumably as a result of livestock grazing and the attendant reduction in fire frequency (Wright and Bailey 1982, McPherson 1997). At the relatively low densities of woody plants that characterize juniper savannas, low-intensity surface fires still may kill most juniper plants and thus reduce their density, as occurred before Anglo settlement. However, juniper trees grow quickly enough, especially in the presence of livestock and the absence of fire, that fires will no longer kill juniper plants a few years post-establishment. In many cases, fires have been absent long enough from former grassland and savannas to allow the formation of closed-canopy juniper stands with little herbaceous understory. The closed-canopy stands that now dominate many sites rarely burn because fine fuel is inadequate to support fire spread even during hot, dry, windy conditions. Thus, livestock grazing and fire suppression apparently have transformed millions of hectares of grassland and savannas into pinyon-juniper woodlands with attendant alterations in ecosystem function. Considerable effort and much progress have been made in the application of prescribed fires to these systems.

Pinyon-juniper woodlands on more mesic sites, especially those with a conspicuous understory of big sagebrush on the Colorado Plateau or at the higher elevation of Mojave Desert mountains, were characterized by a fire regime that was intermediate in frequency and intensity. Pinyon trees were often sufficiently dense to support the spread of high-intensity crown fires during particularly hot, dry, windy conditions. In these stands, fires were constrained by a combination of fuel accumulation and fuel moisture, but they probably occurred every 50-100 years. They were fueled primarily by woody plants, so that the probability of fire was low until woody plants established and grew to "fill in" after the last fire.

The probability of fire increased as fuels accumulated in the post-fire period. Many decades after a fire, the availability of fuel coincided with an ignition source (usually lightning) and low fuel moisture associated with the hot, dry weather that characterizes the region in May and June. The pre-settlement fire regime has been maintained on many of these sites. On others, interruption of the fire regime is a temporary phenomenon that is maintained only by the considerable fire suppression efforts. Ultimately, these stands will burn. Fire intensity undoubtedly increases with increased time since fire because the woody fuels that support fire spread in these systems continue to accumulate. Thus, the artificial and temporary removal of fires from these systems spawns less frequent but more intense fires in these systems. Such fires may change soil chemistry and soil structure, thereby causing accelerated erosion (e.g., DeBano 2000; Robichaud et al., 2000; Sampson et al., 2000; Ritsema and Dekker 2003).

Relatively tall trees and very infrequent fires characterize the most mesic pinyon-juniper woodlands. When these woodlands burn, fire intensity is adequately high to consume much of the aboveground biomass. Given the centuries-long fire-return intervals that typified these forests before Anglo settlement, it seems reasonable to assume that a century of fire suppression has had minimal impact on stand dynamics or structure. Thus, the contemporary fire regime probably is very similar to the pre-settlement regime. Considering the susceptibility of dominant tree species to fires (especially pinyon) and the fuel and weather conditions associated with historical and contemporary fires, introducing prescribed fires into mesic pinyon-juniper woodlands seems very difficult to accomplish.

Although the fire regime apparently has been largely unaffected by Anglo settlement in the most mesic pinyon-juniper woodlands, the impacts of contemporary fires probably will differ from those of pre-settlement fires. Regional warming and drying as a result of global warming will probably affect tree recruitment patterns. Specifically, establishment of pinyon likely will decline or will be restricted to years with above-average precipitation. Stand-replacing fires in these systems might engender a region-wide reduction in pinyon and a concomitant increase in juniper, sagebrush, and other species typically found on more xeric sites. Rapid warming and drying likely will elevate the likelihood of fire occurrence and intensity in these woodlands, similar to patterns observed (Wotton et al., 2003) and expected (Baker 2003; Flannigan et al., 2003; Miller 2003) in coniferous forests of North America.

Southwestern Shrubland

Southwestern shrublands are extremely diverse, ranging from some of the lowest elevations and arid locations to the interface with middle elevation woodland and some forests. Low elevations below 4,000 ft are typically characterized as creosotebush scrub, dominated by the type-species creosotebush [*Larrea tridentata* (DC.) Coville], which has the highest cover and is the most wide-ranging plant species in the Mojave Desert (Rowlands et al., 1982). This is the low-elevation desert shrubland and grassland zone of Brooks and Minnich (2006). Middle elevations between 4,000 and 6,000 ft are typically characterized by blackbrush scrub in the Mojave Desert, dominated by the type-species, blackbrush (*Coleogyne ramosissima* Torr.). This is the middle-elevation desert shrubland and grassland zone of Brooks and Minnich (2006). Areas slightly above blackbrush in the deserts of California, southern Nevada, and southwestern Utah are often characterized as Arizona chaparral, typically embedded within the upper blackbrush ecotone or the lower pinyon-juniper ecotone (high-elevation desert shrubland and woodland zone, Brooks and Minnich 2006). To the southeast, Arizona chaparral dominates the sub-Mogollan foothill region of Arizona, below the woodlands and forests and above the desert shrublands and grasslands (Pase and Brown 1994). Arizona chaparral is dominated by woody evergreen shrubs with dense crowns such as buckbrush (*Ceonothus* spp.) and manzanita (*Arctostaphylos* spp.).

Pre-settlement fire conditions in creosotebush scrub are largely unknown because the typical analytical methods, such as dendrochronology and evaluating charcoal deposits in lakes, are not possible where the requisite trees and lakes are not present (Brooks and Minnich 2006; Esque and Schwalbe 2002). It is

generally thought that fires were an infrequent event because fine fuels from winter annual plants were probably sparse, only occurring in large amounts after exceptionally wet winters (Brooks and Esque 2002, Brooks and Minnich 2006, Brown and Minnich 1986, Esque and Schwalbe 2002, Salo 2003). Fires were probably more frequent in adjacent shrub-steppe areas where perennial grasses provided additional fuel continuity to carry fire (Brooks et al., 2007). It appears that wildfire was not historically a dominating influence in creosotebush scrub landscapes, except possibly where it intergraded with shrub-steppe.

Fine fuels from nonnative annual grasses currently represent the most important fuelbed component in creosotebush scrub (Rogers and Vint 1987, Brooks and Minnich 2006). Between 1955 and 1983 fire frequency increased in the Sonoran Desert (Schmidt and Rogers 1988), and during the 1980s and early 1990s, fire frequency increased substantially within the Mojave Desert (Brooks and Esque 2002; Brooks and Matchett 2006), and many of these fires occurred in creosotebush scrub. It appears that fine fuels produced during years of high rainfall are largely required for the development of large fires in this vegetation type (Rogers and Vint 1987, Schmidt and Rogers 1988, Brooks and Matchett 2006, Brooks and Minnich 2006). Creosotebush stands in the eastern Sonoran desert can experience similar increased fires due to the invasion of non-native perennial grasses such as Lehmann lovegrass (*Eragrostis lehmanniana* Nees), bufflegrass [*Pennisetum ciliare* L. (Link)] and purple fountaingrass [*Pennisetum setaceum* (Forsk.) Chiov.].

Prior to European contact (pre-settlement), blackbrush stands were probably more extensive than they are today (Brooks et al., 2007). Extensive burning to remove blackbrush for range improvement probably created many of the vegetation stands where blackbrush is either absent or a sub-dominant species today. The historical fuel complex in blackbrush stands was probably similar to that observed in relatively unaltered sites today, except for the current prevalence of brome grasses (*Bromus* spp.) and red-stemmed filaree [*Erodium cicutarium* (L.) Aiton] in many stands (Brooks and Matchett 2003). Shrub cover was likely comprised primarily of blackbrush at 30 to 50 percent total cover, and interspaces were probably mostly bare, even during years of high rainfall, due to root competition from blackbrush. Low amounts of fine fuels in interspaces probably limited fire spread to only extreme fire weather conditions during which high winds, low relative humidity, and low fuel moisture led to high intensity stand-replacing crown fires. Natural fire return intervals appear to have been on the order of centuries (Webb et al., 1987). The long intervals without fire allowed blackbrush stands to re-establish.

The fuel complex in blackbrush appears to be more conducive to burning now than in the past. Nonnative annual grasses currently occur in most blackbrush stands (M. Brooks, personal observations), although their dominance can vary significantly among sites (Brooks and Matchett 2003). Post-fire landscapes are even more dominated by these nonnative grasses, which raises concerns that they will promote recurrent fire and prevent the re-establishment of blackbrush plants. This link between fine fuels and fire size is supported by recent analyses that demonstrate that years of high rainfall, which lead to high production of fine fuels, are correlated with larger fires in the elevations where blackbrush occurs in the Mojave Desert (Brooks and Matchett 2006). This is in contrast to the conclusions of Minnich (2003) who states that fine fuels that respond to short pulses of rainfall have less of an effect on fire regimes in blackbrush than woody fuels that accumulate slowly over time. Both conclusions probably have some validity, with fine fuels taking precedence at lower elevations of the blackbrush zone and woody fuels taking precedence at higher elevations. At lower elevations, spacing between blackbrush plants is often relatively high (~1m [3.3 ft]). This requires fine fuels to carry fire under most circumstances, whereas at higher elevations spacing between blackbrush plants is often relatively small (<50cm [20 in], allowing fire to carry from shrub to shrub during high winds (M. Brooks, personal observation).

Historical fire-return intervals in interior chaparral were likely 50 to 100 years (Cable 1975). However, this is an average over its entire range, and local intervals probably varied widely. Many low-elevation interior chaparral sites have been managed for livestock grazing since the 1880s (Pase and Brown 1994).

Where fire was used to maintain grass forage, interior chaparral probably did not encroach into lower elevation grasslands. However, where fire was not used, and the removal of fine fuels by livestock grazing and fire suppression further decreased the frequency of wildfire, interior chaparral very likely did encroach into lower elevation grasslands. Large areas near the early settlements of Prescott and Globe, Arizona were reported to be grasslands in the 1860s and became dense stands of interior chaparral by 1936 (Cable 1975). Aldo Leopold (1924) reported a substantial increase in “brush” cover since the 1880s at the expense of herbaceous plant cover after 40 years of livestock grazing.

Aldo Leopold made additional observations at the interior chaparral–grassland ecotone in southern Arizona, which sheds some light on the pre-settlement fire regime of this region. He noted during the early 1920s that there were multiple fire scars on ancient juniper stumps embedded in even-aged chaparral stands consisting of shrubs <40 years old. This suggests that the fire scars were created during low-intensity grassland fires that pre-dated the current chaparral stands (Leopold 1924). Based on observations such as these, Leopold concluded that there had been no widespread fires in the chaparral-grassland ecotone in southern Arizona between the early 1880s and early 1920s. He further hypothesized that previous grassland fires at these same sites occurred at intervals of approximately once every 10 years before the advent of widespread livestock grazing.

High-elevation interior chaparral sites likely did not receive as much grazing pressure, but fire suppression, especially at the interface with ponderosa pine forests, may have resulted in forest encroachment into chaparral shrublands. For example, where old chaparral stands intergrade with woodlands or forests at higher elevations, chaparral species such as Pringle manzanita (*Arctostaphylos pringlei* Parry) and Fendler ceanothus (*Ceanothus fendleri* A. Gray) may be replaced by ponderosa pine, Emory oak (*Quercus emoryi* Torr.), or Arizona oak (*Quercus arizonica* Sarg.) after long fire-free intervals (Pase and Brown 1994).

Interior chaparral presents a more complex management challenge than the forests above or the deserts below, facing some of the challenges of both. Like the ponderosa pine forests, chaparral communities are fire-dependant. Exclusion of fire from interior chaparral can lead to encroachment by woodland and forest species. Like the creosotebush scrub and blackbrush desert shrublands, non-native annual grasses can increase fire frequency to the point where even the fire-adapted interior chaparral cannot recover. Thus, interior chaparral requires fire, but not too much fire.

Southwestern Grassland

Southwestern grasslands typically are found between 3,500 feet and 5,500 feet south and east of the Mogollon Rim in Arizona and New Mexico. They are bordered by oak- or juniper-dominated woodlands at higher elevations and by xeric communities dominated by woody plants at lower elevations (e.g., desert scrub or semi-desert shrub/grassland) (Brown 1982, pp. 115-131). Southwestern grasslands are dominated by a diverse suite of species assemblages. Kuchler (1964) recognizes grama-buffalograss grasslands in eastern New Mexico, wheatgrass-needlegrass grasslands on the Colorado Plateau, and grama-tobosa prairie in southeastern Arizona and southern New Mexico. Various authors split the grasslands of southeastern Arizona and southern New Mexico into two types: semi-desert grassland and plains grassland (e.g., Brown 1982). The semi-desert grassland can be further divided into grasslands dominated by black grama (*Bouteloua eriopoda* Torr.) and those in which black grama is uncommon or absent. Despite the variety of physiographic settings and consequent diversity of dominant species, issues surrounding fuels management are similar in these grass-dominated systems. Therefore, they are combined into a single section for this discussion.

Cool-season (C_3) grasses mix with warm-season (C_4) grasses on the Colorado Plateau west of the Continental Divide. This grassland represents the southern extension of the sagebrush-grass system that

dominates the Great Basin, and the rich array of grasses reflects species found in adjacent sagebrush-dominated sites: Galleta [*Hilaria jamesii* (Torr.) Benth.], several species of grama (*Bouteloua*), dropseed (*Sporobolus*), bluegrass (*Poa*), and needle-and-thread (*Stipa*) are a few of the common taxa. South and east, cool-season grasses may be present but warm-season grasses assume dominance. Grasses of the following genera are particularly prevalent: grama, three-awns (*Aristida*), muhly (*Muhlenbergia*), and dropseed. Floodplains usually are dominated by tobosa [*Hilaria mutica* (Buckl.) Benth.] and sacaton (*Sporobolus wrightii* Munro).

Historical accounts suggest that extensive fires occurred frequently in most of the region's grasslands. Mean time between fires probably was 5 to 15 years. However, there was considerable variability around the mean on a site, such that fire-free periods likely ranged from 2 to 30 years (Humphrey 1958; Humphrey and Mehrhoff 1958; Wright and Bailey 1982; McPherson 1995). These fires typically occurred in late June or early July when the first summer thunderstorms moved into the region after the extended hot, dry period in May and June.

Many woody plants found in these grasslands are susceptible to fire, especially as seedlings (Bock and Bock 1992), and few of the woody plants resprout if they are burned as seedlings (Glendening and Paulsen 1955; Wright and Bailey 1982). Fires also kill seeds of woody plants found on the soil surface (Cox et al., 1993). Many of the region's woody plants produce seeds only after they are at least 10 years old (Humphrey 1958, Burns and Honkala 1990a, 1990b), which suggests that relatively frequent fires helped prevent the establishment of woody plants. In contrast, most grasses experience a period of reduced productivity shorter than three years (Wright and Bailey 1982). These differences in post-fire response likely gave grasses a competitive advantage and helped prevent shrub encroachment before Anglo settlement.

When livestock were introduced throughout the region in the late 1800s, the concomitant reduction in fine fuels reduced the probability of fire spread, thus contributing to a rapid decline in fire occurrence and increased dominance by woody plants (McPherson 1995). On many sites, woody plants now interfere with grass production to the extent that fires rarely spread, even under climatic conditions that are extremely hot, dry, and windy.

Fire is not crucial for preventing shrub establishment in some plains grassland sites, especially compared to nearby semi-desert grassland. Woody plants associated with plains grassland tend to be smaller than those associated with semi-desert grassland, perhaps because of colder temperatures or edaphic constraints in plains grasslands. As a result, the positive relationship between fire occurrence and grasses is less obvious on plains grassland than in most other southwestern grasslands (Dick-Peddie 1993, Paysen et al., 2000).

In contrast to most other grasslands of the region, historical fires apparently were uncommon in grasslands dominated by black grama. There is a paucity of historical evidence for widespread fires in southern New Mexico where black grama dominated semi-desert grasslands. In addition, the slow post-fire recovery of this species, particularly when fires are followed by below-average precipitation, suggests that it could not dominate sites subject to frequent fires (Buffington and Herbel 1965).

Nonnative perennial grasses, especially Lehmann lovegrass, have invaded large portions of semi-desert grassland in southern Arizona during the last 60 years (Ruyle et al., 1988; Cox et al., 1990; Anable et al., 1992). Prescribed fires, which typically are conducted during March and April, favor Lehmann lovegrass, thereby perpetuating the establishment and spread of this grass. Nonnative grasses such as Lehmann lovegrass typically produce more biomass than native grasses, especially during years of below-average precipitation, and they have a high C:N ratio that makes them slow to decompose. These systems, in which fire spread is limited by fuel abundance and continuity, are therefore subject to more frequent fires

when nonnative grasses become dominant (McPherson and Weltzin 2000). However, expected increases in fire extent have been suppressed through the combination of livestock grazing, woody plant dominance, effective fire suppression, and fragmentation from roads and other developments that have contributed to regional reductions in fuel abundance and continuity. As such, fires now occur very rarely on most grassland sites.

The infrequent fires that occur in these grasslands usually burn during two distinct seasons. Prescribed fires usually are conducted during March and April, when relatively cool temperatures facilitate control. Wildfires—and rarely, prescribed fires—occur in late June, which corresponds to the historical fire season. Effects of spring fires are largely unknown, especially for the many ecosystem functions and unnoticed species that are rarely monitored. The primary exception concerns Lehmann lovegrass which responds positively to prescribed fires conducted during March and April, thereby perpetuating the establishment and spread of this species. Impacts of summer fires, including prescribed fires, demand further study throughout these grasslands. In the absence of further study, prescribed fires should augment wildfires during the critical summer season; when they historically occurred. These fires undoubtedly will enhance long-term preservation of biological diversity because they correspond to the fire season with which native species evolved.

Literature Cited

Agee, James K.; Wright, Clinton S.; Williamson, Nathan; Huff, Mark H. 2002. Foliar moisture content of Pacific Northwest vegetation and its relation to wildland fire behavior. Forest Ecology and Management 167: 57-66.

Alexander, Robert R. 1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: the status of our knowledge. Research Paper RM-121. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 88 p.

Alexander, Robert R. 1987. Ecology, silviculture, and management of the Engelmann spruce-subalpine fir type in the central and southern Rocky Mountains. Handbook 659. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 144 p.

Anable, Michael E.; McClaran, Mitchel P.; Ruyle, George B. 1992. Spread of introduced Lehmann lovegrass (*Eragrostis lehmanniana* Nees.) in southern Arizona, USA. Biological Conservation 61: 181-188.

Archer, Steve. 1994. Woody plant encroachment into southwestern grasslands and savannas: rates, patterns and proximate causes. In: Vavra, Martin; Laycock, William A.; Pieper, Rexford D., editors. Ecological Implications of Livestock Herbivory in the West. Denver, CO: Society for Range Management: 13-68.

Baisan, Christopher H.; Swetnam, Thomas W. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, USA. Canadian Journal of Forest Research 20: 1559-1569.

Baisan, Christopher H.; Swetnam, Thomas W. 1995. Management implications of historical fire occurrence patterns in remote mountains of southwestern New Mexico and northern Mexico. In: Brown, James K.; Mutch, Robert W., Supon, C.W.; Wakimoto, Ron H, technical coordinators. Proceedings: Symposium on Fire in Wilderness and Park Management, Missoula, MT, March 30-April 1, 1993. General Technical Report INT-320. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 153-156.

Baker, William L. 2003. Fires and climate in forested landscapes of the U.S. Rocky Mountains. In: Veblen, Thomas T.; Baker, William L.; Montenegro, Gloria; Swetnam, Thomas W., editors. Fire and Climatic Change in Temperate Ecosystems of the Western Americas. New York, NY: Springer-Verlag: 120-157.

Baker, William L.; Ehle, Donna. 2001. Uncertainty in surface-fire history: the case of ponderosa pine forests in the western United States. Canadian Journal of Forest Research 31: 1205-1226.

Baker, William L.; Ehle, Donna. 2003. Uncertainty in fire history and restoration of ponderosa pine forests in the western United States. In: Omi, Philip N.; Joyce, Linda A., technical editors. Fire, Fuel Treatments, and Ecological Restoration: Conference Proceedings. Proceedings RMRS-P-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 319-333.

Bessie, W.C.; Johnson, E. A. 1995. The relative importance of fuels and weather on fire behavior in sub-alpine forests. Ecology 76: 747-762.

Bilgili, Ertugrul. 2003. Stand development and fire behavior. Forest Ecology and Management 179: 333-339.

Bock, Carl E.; Bock, Jane H. 1992. Response of birds to wildfire in native versus exotic Arizona grassland. Southwestern Naturalist 37: 73-81.

Bradley, R. S.; Hughes, M. K.; Diaz, H. F. 2003. Climate in medieval time. Science 302: 404-405.

Brooks, M.L.; Esque, T.C. 2002. Non-native plants and fire in desert tortoise (*Gopherus agassizii*) habitat of the Mojave and Colorado Deserts. Chelonian Conservation Biology. 4: 330-340.

Brooks, M.L, Esque, T.C., and Duck, T.A. 2007. Creosotebush, blackbrush, and interior chaparral. Pp. 97-110 in Hood, S. and M. Miller (eds.). Fire ecology and management of the major ecosystems of southern Utah. USFS, Rocky Mountain Research Station. General Technical Report RMRS-GTR-202.

Brooks, M.L.; Matchett, J.R. 2003. Plant community patterns in unburned and burned blackbrush (*Coleogyne ramosissima*) shrublands in the Mojave Desert. Western North American Naturalist. 63: 283-298.

Brooks, M.L.; Matchett, J.R. 2006. Spatial and temporal patterns of wildfires in the Mojave Desert. 1980-2004. Journal of Arid Environments. 67: 148-164.

Brooks, M.L.; Minnich, R.A. 2006. Southeastern Deserts Bioregion. In: Sugihara, Neil G.; van Wagtendonk, Jan W.; Shaffer, Kevin E.; Fites-Kaufman, JoAnn; Thode, Andrea E., eds. Fire in California's ecosystems. Berkeley, CA: The University of California Press: 391-414.

Brown, David E., editor. 1982. Biotic communities of the American Southwest–United States and Mexico. Desert Plants 4(1-4): 1-342.

Brown, Peter M.; Kaufmann, Merrill R.; Shepperd, Wayne D. 1999. Long-term, landscape patterns of past fire events in a montane ponderosa pine forest of central Colorado. Landscape Ecology 14: 513-532.

Brown, D.E.; Minnich, R.A. 1986. Fire and creosote bush scrub of the western Sonoran Desert, California. American Midland Naturalist. 116: 411-422.

Buffington, Lee C.; Herbel, Carlton H. 1965. Vegetational changes on a semidesert grassland range from 1858 to 1963. Ecological Monographs 35: 139-164.

Burns, Russell M.; Honkala, Barbara H., technical coordinators. 1990a. Silvics of North America. Volume 1, Conifers. Agricultural Handbook 654. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 675 p.

Burns, Russell M.; Honkala, Barbara H., technical coordinators. 1990b. Silvics of North America: Volume 2, Hardwoods. Agriculture Handbook 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.

Cable, Dwight R. 1975. Range management in the chaparral type and its ecological basis: the status of our knowledge. Research Paper RM-155. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 30 p.

Cox, Jerry R.; Ibarra, F.A.; Martin, M.H. 1990. Fire effects on grasses in semiarid deserts. In: Krammes, J. S., technical coordinator. Effects of Fire Management of Southwestern Natural Resources: Proceedings of a Symposium, November 15-17, 1988, Tucson, AZ. General Technical Report RM-191, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 43-49.

Cox, Jerry R.; De Alba-Avila, A.; Rice, Richard W.; Cox, J.N. 1993. Biological physical factors influencing *Acacia constricta* and *Prosopis velutina* establishment in the Sonoran desert. Journal of Range Management 46: 43-48.

Crowley, T. J. 2000. Causes of climate change over the past 1000 years. Science 289: 270-277.

Danzer, Shelley R.; Baisan, Chris H.; Swetnam, Thomas W. 1996. The influence of fire and land-use history on stand dynamics in the Huachuca Mountains of southeastern Arizona. In: Ffolliott, Peter F.; DeBano, Leonard F.; Baker, Malchus B., Jr.; Gottfried, Gerald J.; Solis-Garza, Gilberto; Edminster, Carleton B.; Neary, Daniel B.; Allen, Larry S.; Hamre, R. H., technical coordinators. Effects of Fire on Madrean Province Ecosystems: A Symposium Proceedings. General Technical Report RM-GTR-289, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 265-270.

DeBano, L.F. 2000. Water repellency in soils: a historical overview. Journal of Hydrology 231-232: 4-32.

Dick-Peddie, William A. 1993. New Mexico Vegetation: Past, Present and Future. Albuquerque: University of New Mexico Press. 244 p.

Dye, A. J. and Moir, William H. 1977. Spruce-fir forest at its southern distribution in the Rocky Mountains, New Mexico. American Midland Naturalist 97: 133-146.

Dyer, James M.; Moffett, K. Evan. 1999. Meadow invasion from high-elevation spruce-fir forest in south-central New Mexico. Southwestern Naturalist 44: 444-456.

Ehle, Donna; Baker, William L. 2003. Disturbance and stand dynamics in ponderosa pine forests in Rocky Mountain National Park, USA. Ecological Monographs 73: 543-566.

Esque, T.C.; Schwalbe, C.R. 2002. Non-native annual plants and their relationships to fire and biotic change in Sonoran Desertscrub. In: Tellman, B., ed. Invasive exotic species in the Sonoran region. Tucson, Arizona: Arizona-Sonora Desert Museum and The University of Arizona Press: 165-194.

Flannigan, Mike; Stocks, Brian; Weber, Mike. 2003. Fire regimes and climatic change in Canadian forests. In:Veblen, Thomas T.; Baker, William L.; Montenegro, Gloria; Swetnam, Thomas W., editors. Fire and Climatic Change in Temperate Ecosystems of the Western Americas. New York, NY: Springer-Verlag: 97-119.

Fulé, Peter Z.; McHugh, Charles; Heinlein, Thomas A.; Covington, W. Wallace. 2001. Potential fire behavior is reduced following forest restoration treatments. In: Vance, Regina K.; Edminster, C.

B., Covington, W. W.; Blake, J. A., compilers. Ponderosa Pine Ecosystems Restoration and Conservation: Steps Toward Stewardship. Proceedings RMRS-P-22. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 28-35.

Fulé, Peter Z.; Covington, W. Wallace; Moore, Margaret M.; Heinlein, Thomas A.; Waltz, Amy E.M. 2002. Natural variability in forests of the Grand Canyon, USA. Journal of Biogeography 29: 31-47.

Fulé, Peter Z.; Crouse, Joseph E.; Heinlein, Thomas A.; Moore, Margaret M.; Covington, W. Wallace; Verkamp, Greg. 2003a. Mixed-severity fire regime in a high-elevation forest of Grand Canyon, USA. Landscape Ecology 18: 465-486.

Fulé, Peter Z.; Heinlein, Thomas A.; Covington, W. Wallace; Moore, Margaret M. 2003b. Assessing fire regimes on Grand Canyon landscapes with fire-scar and fire-record data. International Journal of Wildland Fire 12: 129-145.

Glendening, G. E.; Paulsen, H. A. Jr. 1955. Reproduction and establishment of velvet mesquite as related to invasion of semidesert grasslands. U.S. Department of Agriculture Technical Bulletin 1127. 50 p.

Grissino-Mayer, Henri D.; Baisan, Christopher H.; Swetnam, Thomas W. 1995. Fire history in the Pinaleno Mountains of southeastern Arizona: effects of human-related disturbances. In: DeBano, Leonard F.; Gottfried, Gerald J.; Hamre, Robert H.; Edminster, Carleton B.; Ffolliott, Peter F.; Ortega-Rubio, A., technical coordinators. Biodiversity and Management of the Madrean Archipelago: The Sky Islands of Southwestern United States and Northern Mexico, September 19-23, 194, Tucson, Arizona. General Technical Report RM-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Station: 399-407.

Humphries, H. C.; Bourgeron, P. S. 2003. Environmental responses of *Pinus ponderosa* and associated species in the south-western USA. Journal of Biogeography 30 (2): 257-276.

Humphrey, Robert R. 1958. The desert grassland. Botanical Review 24: 193-253.

Humphrey, Robert R.; Mehrhoff, L. A. 1958. Vegetation changes on a southern Arizona grassland range. Ecology 39: 720-726.

Johnson, E. A.; Miyanishi, K; Bridge, S. R. J. 2001. Wildlife regime in the boreal forest and the idea of suppression and fuel buildup. Conservation Biology 15: 1554-1557.

Jones, John R. 1974. Silviculture of southwestern mixed conifers and aspen: the status of our knowledge. Research Paper RM-122. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 44 p.

Kafka, Victor; Gauthier, Sylvie; Bergeron, Yves. 2001. Fire impacts and crowning in the boreal forest: study of a large wildfire in western Quebec. International Journal of Wildland Fire 10: 119-127.

Kaib, J. Mark; Baisan, Christopher H.; Grissino-Mayer, Henri D.; Swetnam, Thomas W. 1996. Fire history in the gallery pine-oak forests and adjacent grasslands of the Chiricahua Mountains of Arizona. In: DeBano, Leonard F.; Gottfried, Gerald J.; Hamre, Robert H.; Edminster, Carleton B.; Ffolliott, Peter F.; Ortega-Rubio, A., technical coordinators. Biodiversity and Management of the Madrean Archipelago: The Sky Islands of Southwestern United States and Northern Mexico, September 19-23, 194, Tucson, Arizona. General Technical Report RM-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Station: 253-264.

Kuchler, A. W. 1964. United States [Potential natural vegetation of the conterminous United States]. Special Publication No. 36. New York: American Geographical Society. 1:3,168,000; colored.

Leopold, Aldo. 1924. Grass, brush, timber and fire in southern Arizona. Journal of Forestry 22: 1-10.

McPherson, Guy R. 1995. The role of fire in the desert grasslands. In: M. P. McClaran, Mitchel P.; Van Devender, Thomas R., editors. The Desert Grassland. Tucson, AZ: University of Arizona Press: 130-151.

McPherson, Guy R. 1997. Ecology and Management of North American Savannas. University of Arizona Press, Tucson. 208 p.

McPherson, Guy R.; Boutton, Thomas W.; Midwood, Andrew J. 1993. Stable carbon isotope analysis of soil organic matter illustrates vegetation change at the grassland/woodland boundary in southeastern Arizona, USA. Oecologia 93: 95-101.

McPherson, Guy R.; Weltzin, Jake F. 2000. The role and importance of disturbance and climate change in U.S./Mexico borderlands: a state-of-the-knowledge review. General Technical Report RMRS-GTR-50. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p.

Miller, Carol. 2003. Simulation of effects of climatic change on fire regimes. In:Veblen, Thomas T.; Baker, William L.; Montenegro, Gloria; Swetnam, Thomas W., editors. Fire and Climatic Change in Temperate Ecosystems of the Western Americas. New York, NY: Springer-Verlag : 69-94.

Moir, Will H.; Ludwig, J. A. 1979. A classification of spruce-fir and mixed conifer habitat types of Arizona and New Mexico. Research Paper RM-207. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Pase, C.P. and D.E. Brown. 1994. Interior chaparral. In: Brown, D.E., ed. Biotic communities: Southwestern United States and Northwestern Mexico. Salt Lake City, UT: University of Utah Press: 95-99.

Paysen, T. E.; Ansley, Richard J.; Brown, James K.; Gottfried, Gerald J.; Hasse, Sally M.; Harrington, Michael G.; Narog, Marcia G.; Sackett, Stephen S.; Wilson, Ruth C. 2000. Fire in Western Shrubland, Woodland, and Grassland Ecosystems. In: Brown, James K.; Smith, Jane Kapler, editors. Wildland Fire in Ecosystems: Effects of Fire on Flora. U.S. Department of Agriculture, Forest Service General Technical Report RMRS-GTR-42-volume 2: 121-159.

Peet, Robert K. 1988. Forests of the Rocky Mountains. In: Barbour, Michael G.; Billings, W. Perry, Jesse P., Jr. 1991. The Pines of Mexico and Central America. Portland, OR: Timber Press. 231 p.

Pierce, Jennifer L.; Meyer, Grant A; Jull, A. J. Timothy. 2004. Fire-induced erosion and millennial-scale climate change in northern ponderosa pine forests. Nature 432: 87-90.

Pollet, Jolie and Philip N. Omi. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. International Journal of Wildland Fire 11: 1-10.

Ritsema, C.J.; Dekker, L.W., editors. 2003. Soil Water Repellency: Occurrence, Consequences, and Amelioration. New York, NY: Elsevier. 352 p.

Robichaud, P.R.; Beyers, Janice L.; Neary, Daniel G. 2000. Evaluating the effectiveness of postfire rehabilitation treatments. General Technical Report RMRS-GTR-63. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Rogers, G.F. and M.K. Vint. 1987. Winter precipitation and fire in the Sonoran Desert. Journal of Arid Environments 13:47-52.

Romme, William H.; Floyd-Hanna, Lisa; Hanna, David D. 2003. Ancient piñon-juniper forests of Mesa Verde and the West: A cautionary note for forest restoration programs. In: Omi, Philip N.; Joyce, Linda A., technical editors. Fire, Fuel Treatments, and Ecological Restoration: Conference

Proceedings. Proceedings RMRS-P-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 335-350.

Rowlands, P.G.; Johnson, H.B.; Ritter, E.; Endo, A. 1982. The Mojave Desert. In: Bender, G.L., ed. Reference handbook of North American deserts. Connecticut: Greenwood Press: 103-159.

Ruyle, George B.; Roundy, Bruce A.; Cox, Jerry R. 1988. Effects of burning on germinability of Lehmann lovegrass. Journal of Range Management 41: 404-406.

Salo, L.F. 2003. Ecology and biogeography of red brome (*Bromus madritensis* subspecies *rubens*) in western North America. Tucson, AZ: University of Arizona. Dissertation.

Sampson, R. Neil; Atkinson, R. Dwight; Lewis, Joe W., editors. 2000. Mapping Wildfire Hazards and Risks. New York, NY: Haworth Press. 343 p.

Schmidt, M.K. and G.F. Rogers. 1988. Trends in fire occurrence in the Arizona upland subdivision of the Sonoran Desert. The Southwestern Naturalist 33:437-444.

Seklecki, Mariette T.; Grissino-Mayer, Henri D.; Swetnam, Thomas W. 1996. Fire history and the possible role of Apache-set fires in the Chiricahua Mountains of southeastern Arizona. In: Ffolliott, Peter F.; DeBano, Leonard F.; Baker, Malchus B., Jr.; Gottfried, Gerald J.; Solis-Garza, Gilberto; Edminster, Carleton B.; Neary, Daniel B.; Allen, Larry S.; Hamre, R. H., technical coordinators. Effects of Fire on Madrean Province Ecosystems: A Symposium Proceedings. General Technical Report RM-GTR-289, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 238-246.

Shea, K. L. 1985. Demographic aspects of coexistence in Engelmann spruce and subalpine fir. American Journal of Botany 72: 1823-1933.

Shinneman, D. J.; Baker, William L. 1997. Nonequilibrium dynamics between catastrophic disturbances and old-growth forests in ponderosa pine landscapes of the Black Hills. Conservation Biology 11: 1276-1288.

Shreve, Forrest. 1915. The Vegetation of a Desert Mountain Range as Conditioned by Climatic Factors. Washington, DC: Carnegie Institute Publication 217. 112 p.

Stromberg, Julie C.; Patten, Duncan C. 1991. Dynamics of the spruce-fir forests on the Pinaleno Mountains, Graham Co., Arizona. Southwestern Naturalist 36: 37-48.

Swetnam, Thomas W. 1990. Fire history and climate in the southwestern United States. In: Krammes, J. S., technical coordinator. Effects of Fire Management of Southwestern Natural Resources: Proceedings of a Symposium, November 15-17, 1988, Tucson, AZ. General Technical Report RM-191, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 6-17.

Swetnam, Thomas W.; Baisan, Chrisopher H. 1996. Fire histories of montane forests in the Madrean borderlands. In: Ffolliott, Peter F.; DeBano, Leonard F.; Baker, Malchus B., Jr.; Gottfried, Gerald J.; Solis-Garza, Gilberto; Edminster, Carleton B.; Neary, Daniel B.; Allen, Larry S.; Hamre, R. H., technical coordinators. Effects of Fire on Madrean Province Ecosystems: A Symposium Proceedings. General Technical Report RM-GTR-289, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 15-36.

Touchan, Ramzi; Allen, Craig D.; Swetnam, Thomas W. 1996. Fire history and climatic patterns in ponderosa pine and mixed-conifer forests of the Jemez Mountains, northern New Mexico. In: Allen, Craig D., technical editor. Fire Effects in Southwestern Forests: Proceedings of the Second La Mesa Fire Symposium. General Technical Report RM-GTR-286, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 33-46.

Webb, R.H.; Steiger, J.W.; Turner, R.M. 1987. Dynamics of Mojave Desert assemblages in the Panamint Mountains, California. Ecology 68: 478-490.

Wotton, B. M.; Martell, D. L.; Logan, K. A. 2003. Climate change and people-caused forest fire occurrence in Ontario. Climatic Change 60: 275-295.

Wright, Henry A.; Bailey, Arthur W. 1982. Fire Ecology: United States and Southern Canada. New York, NY: John Wiley. 501 p.

Hydrology and Ecology of Intermittent Stream and Dry Wash Ecosystems

Lainie Levick, USDA-ARS; David Goodrich, USDA-ARS; Mariano Hernandez, USDA-ARS; Darius Semmens, USEPA, ORD; Juliet Stromberg, Arizona State University; Rob Leidy, USEPA, Office of Water, Region IX; Melissa Apodaca, USEPA, Office of Water, Region IX; D. Philip Guertin, University of Arizona; Melanie Tluczek, Arizona State University; William Kepner, USEPA, ORD

Abstract

Ephemeral (dry washes) and intermittent streams make up approximately 59% of all streams in the U.S. (excluding Alaska), and over 81% in the arid and semi-arid Southwest (Arizona, New Mexico, Nevada, Utah, Colorado and California) according to the National Hydrography Dataset. They are often the headwaters or major tributaries of most perennial streams in the Southwest, and make up 94% of stream miles in Arizona. Given their vast extent, ephemeral and intermittent streams are crucial to the overall health of a watershed, providing a wide array of functions including forage, cover, nesting, and movement corridors for wildlife. Because of the relatively higher moisture content in dryland streams, vegetation and wildlife abundance and diversity is higher than in the surrounding uplands. Ephemeral and intermittent streams provide the same hydrologic functions as perennial streams by moving water, nutrients, and sediment through the watershed. When functioning properly, dryland streams provide many of the same services as perennial riparian-wetland areas, such as landscape hydrologic connections; stream energy dissipation during high-water flows that reduces erosion and improves water quality; surface and subsurface water storage and exchange; groundwater recharge and discharge; sediment transport, storage, and deposition aiding in floodplain maintenance and development; nutrient cycling; wildlife habitat and movement/migration; support for vegetation communities that help stabilize stream banks and provide wildlife services; and water supply and water-quality filtering. Ecologically sustainable land and wildlife management requires a landscape or watershed-scale approach to ecosystem protection, and would be meaningless and ineffective if these supporting waterways are significantly degraded.

Introduction

Intermittent and ephemeral streams, or dry washes, are found in the arid and semi-arid regions of the Earth that are commonly referred to as “drylands”. Nearly one-third of the Earth’s land surfaces are classified as arid or semi-arid (Whitford, 2002). These lands are characterized by low and highly variable annual precipitation, where annual evapotranspiration exceeds precipitation. It is precisely because of these dry conditions, which result in great contrast between the moist riparian areas and adjacent dry upland communities, that these streams are so important. The US EPA, using the National Hydrography Dataset (NHD; USGS, 2006), has estimated that 59% of U.S. streams (excluding Alaska) are ephemeral or intermittent (U.S. EPA, 2005). Nearly 81% of all streams in the six Southwestern states (Arizona, New Mexico, Nevada, Utah, Colorado and California) are ephemeral or intermittent (calculated from the National Hydrography Dataset, http://nhd.usgs.gov/).

Ephemeral and intermittent streams are often the headwaters or major tributaries of most perennial streams in the arid and semi-arid Southwest. When functioning properly, these dryland streams provide many of the same services as perennial riparian-wetland areas, such as landscape hydrologic connections; stream energy dissipation during high-water flows that reduces erosion and improves water quality; surface and subsurface water storage and exchange; groundwater recharge and discharge; sediment transport, storage, and deposition aiding in floodplain maintenance and development; nutrient transport and cycling; wildlife habitat and movement/migration; support for vegetation communities that help

stabilize stream banks and provide wildlife services; and water supply and water-quality filtering (USFWS, 1993; BLM, 1998).

These functions depend on the balance and interactions between water, vegetation, soil, and geology. Sustainability and resilience to disturbance are also important characteristics in dryland stream systems when addressing ecologically sustainable land management. Because of the lack of water, dryland ecosystems do not recover quickly from disturbance. The disturbance or loss of ephemeral and intermittent streams has dramatic physical, biological, and chemical impacts which are evident from the uplands to the riparian areas or stream courses of the watershed. The amount of precipitation that immediately runs off the land surface, and infiltrates into the soil to either be used for plant growth or to recharge ground water, is dependent on this critical interface (Barnett et al., 2002). Ecologically sustainable land management requires a landscape or watershed-scale approach to ecosystem protection, and would be meaningless and ineffective if these supporting waterways are significantly degraded.

Hydrologic Considerations

A stream can be defined as a natural body of flowing water, either on the surface or below. It can be perennial, intermittent or ephemeral. Ephemeral streams (or dry washes), and intermittent streams are the chief characteristic of drylands. An *ephemeral stream* may be defined as a stream or portion of a stream which flows briefly in direct response to precipitation in the immediate vicinity, and whose channel is at all times above the water table elevation. An *intermittent stream* is one where portions of the stream flow continuously only at certain times of the year, for example when it receives water from a spring or from a surface source, such as melting snow (i.e. seasonal).

These two stream types differ greatly from a *perennial stream*, which is defined as a stream that flows on the surface continuously throughout the year, and is considered permanent. Baseflow of a perennial stream is maintained by groundwater discharge to the stream bed, and the water-table elevation adjacent to the stream is typically greater than the surface-water elevation within the stream.

In addition to their chief attribute of lacking perennial flow, ephemeral and intermittent streams in drylands also experience extreme variations in flood regime, rarely reaching process-form equilibrium due to irregular flows. They have high rates of sediment transport, and show a relationship between flood magnitude and duration with the size of the watershed (Reid and Frostick, 1989; North, 2005). Biophysical characteristics such as channel geometry, morphology, and plant-community type are dependent on where an ephemeral or intermittent channel originates. Steep watersheds will have different features, such as alluvial fans and bajadas, than watersheds of gently rolling hills (Whitford, 2002).

Most streamflow events in a good portion of the Sonoran and Chihuahuan Deserts occur during the summer monsoon (July through September) from high-intensity, short-duration rainfall events which typically occur as air-mass thunderstorms resulting from convective heating of moisture-laden air masses (Gochis et al., 2006). Streamflow may last only minutes or hours, or may persist for days or weeks depending on the climatic regime and the nature of the watershed contributing area. Flash floods may occur any time of the year after the watershed has had enough precipitation to generate runoff. Long-duration, lower-intensity events are typical of cool-season precipitation caused by frontal systems originating in the eastern North Pacific Ocean (Hereford et al., 2003). It is relatively rare for ephemeral channels to have significant streamflow from low-intensity cool-season precipitation. Less frequently (approximately three to five percent of the annual rainfall in southern Arizona, on average), runoff and streamflow occurs from the remnants of hurricanes and tropical depressions which track north from lower latitudes. The influence of both the summer monsoon and increases in precipitation from tropical depressions decreases as one moves north.

The high degree of spatial and temporal variability in hydrologic processes and the resulting erosion and sedimentation processes in arid and semi-arid regions as compared to humid regions means that these characteristics cannot be reliably predicted by extrapolation from humid regions (Scott, 2006; McMahon, 1979). Due to sparse vegetation cover and poorly developed soils with little organic matter, it is typical for desert environments to produce more runoff and erosion per unit area than in temperate regions for a given intensity of rainfall (Thornes, 1994). Graf (1988) reported that for a humid region in Pennsylvania, the 50-year return flood event is roughly 2.5 times the mean annual flow, whereas the 50-year return flow for the Gila River in Arizona is about 280 times the mean annual flow. Of the 12 largest floods ever measured in the United States, all occurred in semi-arid to arid regions, and 10 occurred in regions with less than 400 mm (16 in.) of rainfall (Costa, 1987).

Other aspects of dryland floods are highly distinctive. For example, flow hydraulics and roughness coefficients are strongly influenced by the vegetation that commonly grows on the normally dry channel beds to exploit moisture contained in subsurface sediments. Low annual precipitation inevitably means low annual runoff, with interannual variability of runoff increasing as annual totals decrease (McMahon, 1979; Rodier, 1985). In North American arid lands, for instance, the variability of mean annual runoff is about double that for the continental areas as a whole (McMahon, 1979). In addition, given the spatially variable patterns of precipitation and runoff in drylands, for any given watershed size there is a large range in annual runoff totals (Reid and Frostick, 1997). Some studies have noted that a large portion of our watersheds in the western states (up to 90% in Arizona, for example) produce less than 12.7 mm (0.5 in.) runoff per year, but the vast extent of these dryland watersheds makes their total runoff production significant, and their proper management important (Renard, 1970). Figure 1 shows a comparison of the average annual precipitation for the Western U.S. for 1961-1990, and the locations of ephemeral/intermittent and perennial streams from the NHD dataset. Note the correlation between locations with higher average annual rainfall amounts and locations with perennial stream flow.

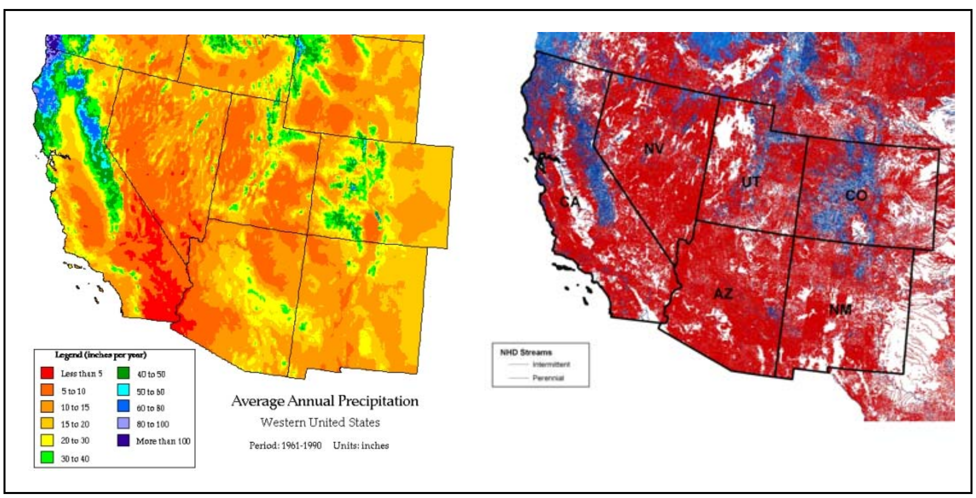


Figure 1. Comparison of average annual precipitation, 1961-1990 (left) with locations of ephemeral/intermittent (red) and perennial (blue) streams (right).
(Western Regional Climate Center, http://www.wrcc.dri.edu/precip.html, and National Hydrography Dataset (NHD), http://nhd.usgs.gov/. Additional information on the NHD is available from their Technical Document "Concepts and Contents", http://nhd.usgs.gov/chapter1/chp1_data_users_guide.pdf).

In a spatial as well as a temporal sense, floods in dryland rivers exhibit some unique characteristics. Regardless of the source of floodwaters, flows in dryland rivers are generally influent, or subject to downstream volume decreases. These decreasing flow volumes principally are due to transmission losses resulting from infiltration of floodwaters into the unconsolidated alluvium forming channel boundaries,

with further losses resulting from overbank flooding and evaporation of floodwaters (Babcock and Cushing, 1942; Keppel and Renard, 1962; Sharp and Saxton, 1962; Lane, 1983; Goodrich et al., 1997). Downstream volume decreases are sometimes negligible along small alluvial rivers or bedrock rivers, but for larger alluvial rivers they can be important, with many flows failing to travel the full length of the channel. Hence, in the absence of appreciable tributary inflows in the lower parts of the watershed, transmission losses produce significant downstream decrease in total flow volume, flood peak, and flow frequencies (Keppel and Renard, 1962; Lane, 1983; Knighton and Nanson, 1997; Goodrich et al., 1997).

An example of transmission losses within the USDA-ARS Walnut Gulch Experimental Watershed near Tombstone, Arizona is presented in Figure 2. The August 27, 1982 storm was isolated in subwatershed 6 on the upper 95 km^2 of the watershed (and not all of that precipitation produced runoff). The runoff measured at the nearest downstream flume, Flume 6, was 246,000 m^3 with a peak discharge of 107 m^3s^{-1}. Runoff traversing 10.86 km of dry streambed between Flume 6 and Flume 1 experienced significant infiltration losses. Total peak discharge was reduced by nearly half to 52 m^3s^{-1}, and 90,800 m^3 of water was absorbed in the channel alluvium.

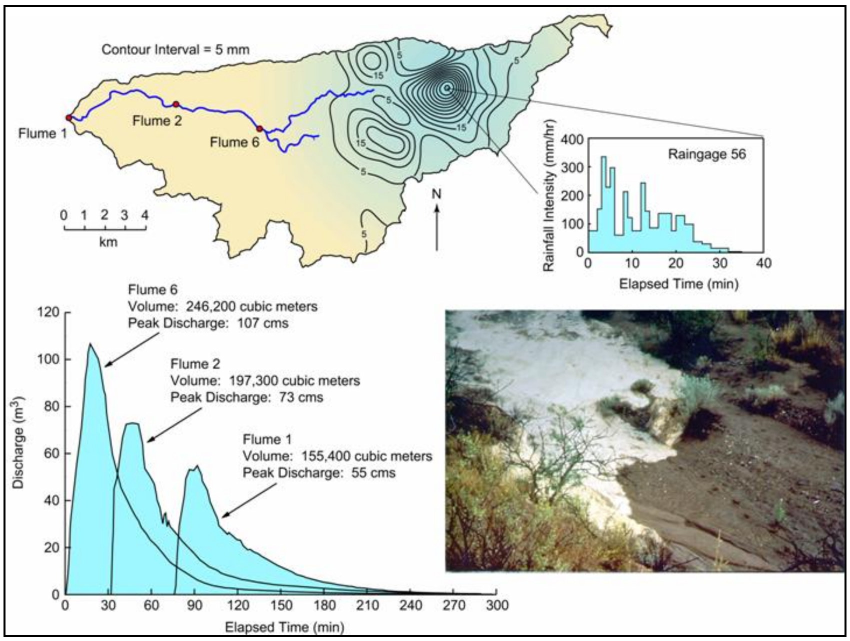


Figure 2. Rainfall-runoff event of August 27, 1982 illustrating ephemeral channel transmission losses and peak flow decreases as measured within the USDA-ARS Walnut Gulch Experimental Watershed near Tombstone, Arizona

As a result of decreased flow rate in the downstream direction, more silts and fines are deposited in the channel which can be advantageous to biotic communities. A study of ephemeral rivers in the Namib Desert (Jacobson et al., 2000) found that "Organic carbon, nitrogen and phosphorous were correlated with silt content, and silt deposition patterns influence patters of moisture availability and plant rooting, creating and maintaining micro-habitats for various organisms." Jacobson concluded that "…alluviation patterns associated with the hydrologic regime strongly influence the structure, productivity, and spatial distribution of biotic communities in ephemeral river ecosystems."

The importance of locally recharged monsoon water derived from ephemeral channel runoff for maintaining flow in the main stem of the San Pedro River was demonstrated by Baillie et al. (2007). Using a suite of geochemical tracers and a two end-member mixing model they found that locally recharged monsoon floodwaters is one of the dominant water sources in the main stem of the San Pedro

River, with these waters comprising 60 to 85% of riparian groundwater in losing reaches of the main stem and 10 to 40% in gaining reaches. Baseflows also contained a significant component of monsoon flood water: 80% at the upstream segment, and decreasing to 55% after several gaining reaches (Baillie et al., 2007).

Although ephemeral or intermittent streams do not contain water at all times, they still perform the major functions of a stream: the transportation of water, nutrients, and sediment. Unlike perennial streams that continuously move sediment through the watershed, sediment movement in ephemeral or intermittent channels occurs as a pulse through the system in response to runoff generated by the short duration, high intensity thunderstorms that result in flash floods. Sediment is also moved from the uplands and hillslopes into the channels from overland flow. The effect is a pulsing style of sediment movement that doesn't always reach the watershed outlet, but is instead remobilized during the next flow and redistributed within the watershed's channel network.

The relative importance of many fluvial processes in arid regions, especially the magnitude and frequency of their operation, differs considerably from more humid regions (Graf, 1988; Thornes, 1994; Bull and Kirkby, 2002). As a result, channel forms also differ considerably from humid regions where the bulk of observations have been made. Although one of the most universally recognized traits of dryland ephemeral channels is their enormous variability in form, a number of broad generalizations have been used to characterize them: 1) They are often closely spaced, resulting in a high drainage density; 2) They have high width-to-depth ratios, are more likely to be braided, and have low sinuosity relative to their humid counterparts; and 3) Bed topography is generally subdued, and often near horizontal and planar.

Ecological Considerations

Miller (2005: p. 18) stated that "the most important functions in dryland ecosystems are those that control the retention of water and nutrient resources because productivity and diversity cannot be sustained in systems that fail to retain these resources". Vegetation in dryland channels plays a key role in resource retention by protecting soils from wind and water erosion, slowing flood velocity, and moderating temperatures.

Vegetation in drylands is largely controlled by the availability of water, with flood disturbance and edaphic conditions further shaping plant distribution patterns. By providing channel and stream bank roughness, vegetation can influence flow velocities, flow depths, bank and floodplain erosion, and sediment transport and deposition, and can be a major factor contributing both to channel stability and to channel instability. In ephemeral or intermittent channels, vegetation may establish on sand bars in channel beds, and subsequently initiate the formation of various depositional features such as small current shadows, bars, benches, ridges or islands (Tooth and Nanson, 2000). Spatially extensive assemblages of any plant species have the potential to alter geomorphology and geomorphic processes through bioturbation, alteration of nutrient or fire cycles, and patterns of succession (Lovich, 1996). Riparian vegetation also influences biogeochemical cycles and water/energy balance, and provides food and cover for wildlife. Changes in the abundance or composition of the plant community thus affect an array of ecosystem functions and processes.

During seasonal dry periods, plant species diversity levels along ephemeral streams typically are low, with values much lower than along perennial streams and also often lower than in adjacent uplands (Leitner, 1987). During seasonal wet periods, however, diversity levels along some ephemeral streams can equal or exceed that of perennial streams (Stromberg, unpublished data). Water from rainfall and flood flows can trigger a pulse of germination of annual and perennial plant species along the ephemeral stream beds. Because the dry-season cover of the woody vegetation is low, and cover of bare soil is fairly high, the seasonal resource pulses can result in very high diversity levels in comparison to that of the

more densely-vegetated perennial streams. Many of the plant species that establish along ephemeral streams during water pulses arise from soil seed banks. Dryland rivers, including ephemeral reaches of spatially intermittent rivers, maintain large and diverse soil seed banks. Rivers that are ephemeral over their entire length (i.e., autogenic desert rivers) have sparser riparian seed banks than do dry reaches of rivers with headwaters in humid mountains (i.e. allogenic desert rivers) (Stromberg, unpublished data).

Diversity varies with seasonal rain and flood patterns, and also varies on longer temporal scales. During periods of sustained runoff, ephemeral washes can support a high density and diversity of wetland (hydroriparian) plant species (Stromberg, unpublished data). These "ephemeral wetland" communities develop with a recurrence interval of perhaps once per decade or more, depending on the flow regime of the particular river.

The biogeochemical features of a riverine system include cycling of elements and compounds, removal of imported elements and compounds, particulate detention, and organic matter transport. These features in ephemeral and intermittent streams are important for determining water quality, sediment deposition, nutrient availability, and biotic functions in both low order streams and downstream perennial waters. Biogeochemical features are affected directly and indirectly by land-use and land-cover change. Hydrologic modifications such as direct alteration of flow regime and hydrologic flow paths, and indirect alterations such as increased impervious cover in contributing areas of the watershed can cause biogeochemical changes. Elimination of the surface water - ground water connection, or disruption of the connection between a stream and its watershed by large scale changes such as urban and suburban development also influence biogeochemical functions (Grimm et. al., 2004).

The variable nature of rainfall in arid environments affects the biogeochemical features of low order streams. These systems are driven by pulse inputs of water, sediment, organic matter, and other materials during rain events. If the rainfall is not sufficient to transport material downstream into larger rivers, the material is stored and processed in the low order streams. This processed material can be transported downstream during large, infrequent storm events. Thus, ephemeral and intermittent streams in arid environments are important for storage and transformation of material and the eventual transport of material downstream to larger rivers.

Various studies have indicated that the periodic flooding of ephemeral or intermittent channels has a strong influence on biogeochemistry by providing a connection between the floodplain and other landscape elements (Valett, et al., 2005). For example, one study on the San Pedro River in Arizona found that approximately 98% of nutrients come into the river during the summer monsoon thunderstorms from ephemeral tributaries, and that almost 60% of that input occurs as a flux of particulate matter (Koch et. al, 2006). Organic material brought into and stored in small low-order streams, can be broken down and transformed into forms more readily available for use by biota in larger perennial streams (Richardson et al. 2005). This was also confirmed by Brooks and Lemon (2007) who concluded that in the San Pedro River, high concentrations of organic matter, and especially high concentrations of nitrogen occurred with the inflow of monsoon runoff from lateral ephemeral tributaries.

Wildlife Concerns

Land management for wildlife has traditionally focused on perennial stream systems and their associated riparian areas, with little attention paid to the importance of tributaries to these perennial streams, which are often ephemeral or intermittent. Because of the concentration of moisture and lush vegetation in ephemeral stream channels in comparison to the surrounding uplands, these areas provide the primary habitat, predator protection, nesting sites, shade, and food sources for wildlife in drylands. The micro-climates created in and around ephemeral streams are utilized extensively by wildlife, and especially by

those species that cannot avoid the harsh desert environment by moving to a more favorable climate. Frequently, these streams may retain the only available water in the area in temporary or perennial pools.

Although the distribution and composition of wildlife species that occur in or utilize ephemeral or intermittent stream systems is not completely understood, the list of species known to be associated with these habitats is long. For example, larger mammals such as deer or bear use riparian vegetation as travel corridors, and smaller mammals such as squirrels, raccoons, or rabbits use it for foraging. Migrating song birds use ephemeral stream corridors extensively as they move through drylands because they contain the densest vegetation, and therefore the best cover and food sources. Reptiles and amphibians rely heavily on dry washes for breeding, and the majority of benthic macroinvertebrates occur in ephemeral and intermittent streams (NWF, 2007).

Most desert species have developed adaptations to the water-limited conditions of drylands, and are habitat and niche specific, allowing them to survive under adverse environmental conditions (Ward, 1973; Louw and Seely, 1982; Williams, 2006). Ward (1973) noted that the life cycles of these species are triggered by specific temperature and/or water conditions, and they may remain dormant or aestivate during unfavorable or stress periods.

Most studies of riparian habitat values have focused on aquatic or avian species. Riparian areas are critical in providing migration stopover sites, and therefore affect the breeding success of northern bird populations (Skagen et al., 1998). Avian species are highly dependent on riparian corridors, whether continuous, discontinuous, ephemeral or perennial. Skagen et al. (1995) looked at the geography of spring bird migration through riparian habitats in the southwest and found that all riparian habitat types were used to some degree. "Riparian habitats" was defined as vegetation communities in association with perennial, ephemeral and intermittent surface and subsurface waters. Skagen et al. (1998) compared the use by migrating birds of riparian corridors versus isolated oases (riverine vegetation isolated from similar vegetation patches) in the San Pedro River of Southern Arizona, and found that "Small, isolated oases hosted more avian species than the corridor sites, and the relative abundance of most migrating birds did not differ between sites relative to size-connectivity." They concluded that the protection of both the small patches and the more extensive riparian corridors is imperative, given the overall habitat limitation in western landscapes.

Although ephemeral streams will only support fish if permanent pools are present, they can still indirectly support fish populations. Cummins and Wilzbach (2005) noted that ephemeral and intermittent streams are important suppliers of invertebrates and detritus to permanently flowing, receiving streams that support juvenile salmonids. Del Rosario and Resh (2000) compared invertebrates in the hyporheic zone in an intermittent and a perennial stream in northern California, and found that intermittent streams had lower densities, similar richness, but higher species diversity than perennial streams.

All amphibians spend at least part of their life cycle in water, sometimes only for breeding. Most reptiles are found near water, although they are not as dependent on it as amphibians (Ohmart and Zisner, 1993). Rosen and Lowe (1996) in their study of herpetofauna at Organ Pipe Cactus National Monument, Arizona, noted that anurans (toads and frogs) are closely tied to permanent or temporary surface water that is long-lasting enough to allow their eggs to hatch and produce tadpoles. As little as 10 days may be required for the desert spadefoot (*Scaphiopus couchi*), with a longer period required for the true toads (genus *Bufo*). They found that anurans bred successfully in temporary pools in major washes and ephemeral springs, and some species of snakes and lizards preferred xeroriparian habitat because of the dense cover. In addition, during drought peaks, almost every other (non-riparian dependent) snake species used the xeroriparian habitat as a refugia against drought periods, although those that normally used that habitat type had a higher survival rate. Xeroriparian habitat was preferred by certain snake species due to higher prey abundance, higher relative humidity, and the presence of denser vegetation for

cover. They also found that lizard species were most abundant in mesquite bosque and xeroriparian habitats (see Figure 3).

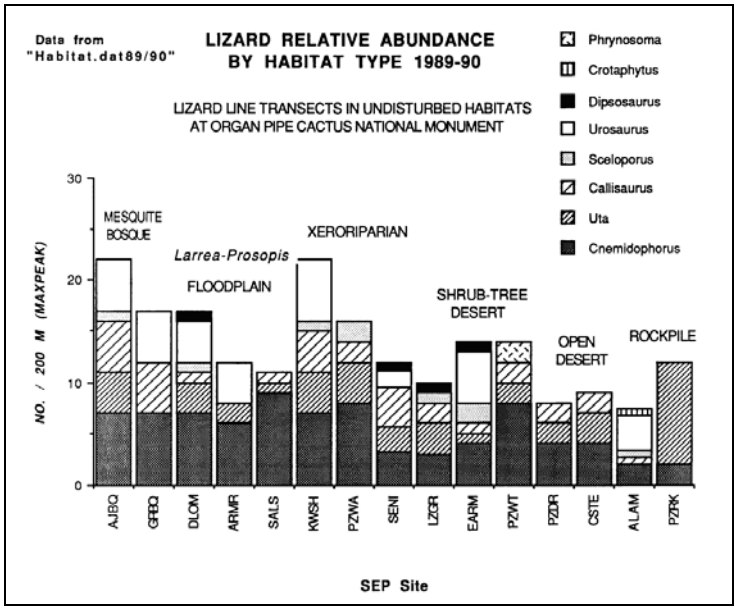


Figure 3. Lizard abundance by habitat type at Organ Pipe Cactus National Monument, (1989-1990), Arizona. Maxpeak refers to maximum peak value observed for all runs of transects within a habitat type at a site. SEP is the Sensitive Ecosystems Program (from Rosen and Lowe, 1996).

A wide variety of mammals inhabits the arid and semiarid southwest, and can utilize temporary and permanent pools found in ephemeral or intermittent streams. Most have adapted to the harsh conditions and lack of water in one or more of the following ways: heat evasion (daily or seasonal estivation, diurnal or nocturnal behavior), water conservation, water storage, dehydration tolerance, heat tolerance, and heat dissipation (open-mouthed gaping, or long appendages such as long ears). Many mammals burrow under ground during the hottest part of the day to avoid the heat and increase water conservation. Others, such as many small rodents, have adapted so they do not need free water at all.

Conclusions and Recommendations

There seems to be little doubt that there are gaps in our understanding of arid and semiarid ecological and hydrological processes that hamper efforts to quantify the natural or modified characteristics of these ecosystems. However, given their large extent, ephemeral or intermittent stream systems are important sources of sediment, water, nutrients, and organic matter for downstream systems and provide habitat for many species (Gomi et al., 2002), and their inclusion is important for watershed-based assessments (Gandolfi and Bischetti, 1997; Miller et al., 1999).

The variability of the hydrological regime is the key determinant of both plant community structure in time and space and the types of plants and wildlife present in dryland streams. Overall, changes to natural hydrological regimes in desert rivers reduce temporal and spatial heterogeneity of plant habitats, resulting in the loss of biodiversity and homogenization of plant community composition and structure. Given the ecological importance of plant communities in desert rivers (e.g. for channel bank stabilization, wildlife habitat), there may be significant secondary impact. There is some evidence to suggest that restoration of natural hydrological regimes in ephemeral streams may be sufficient to partly reverse such deleterious changes in plant communities (see for example, Stromberg, 2001).

The management of arid and semi-arid lands drained by ephemeral channels has a direct impact on the hydrology and geomorphology of the drainage network, in addition to wildlife habitat. Indeed ephemeral streams are much more sensitive to climate or anthropogenic disturbance than perennial streams (Bull, 1997). Anthropogenic disturbances include livestock grazing, land clearing, mining, timber harvesting, groundwater withdrawal, stream flow diversion, channelization, urbanization, agriculture, roads and road construction, off-road vehicle use, camping, hiking, and vegetation conversion. Biological stressors include habitat loss, alteration, and degradation from decline in water quality and changes in channel and flow characteristics (Pima County, 2000). For example, impervious surfaces in urban areas increase the frequency and magnitude of flooding. Storm sewers and lined drainages increase the rate at which these waters are delivered to the channel network, and thus further increase peak flows and erosion. Improperly constructed and maintained roads, especially dirt roads, can cause hill slope drainage alterations, baseflow alterations, and precipitation-runoff relationship alterations, resulting in erosion and sedimentation into the streams (USDA, 2002). The primary geomorphic consequence of these hydrologic changes is the erosional entrenchment of adjacent channels and associated transportation of the excavated sediment further downstream, causing a significant increase in sediment load, which may partly explain why most TMDLs in the Southwest are written for sediment. In addition as streams become entrenched, the floodplains can transform into dry terraces, causing formerly rich biological communities to become hydrologically disconnected from ephemeral streamflow. Additionally, as channels become narrower and unconsolidated alluvial bed material is removed, there is less capacity to absorb passing flows. Given the importance of transmission losses to regional aquifer recharge, long-term negative impacts to groundwater supplies are likely if these flows are not absorbed.

Stream channel characteristics are based on upland watershed and channel conditions. Physical characteristics such as the hydrology of the system drive biological values. Therefore, in order to protect critical riparian habitat, a watershed-based approach to land management must be taken, involving all stakeholders and applying best management practices to control runoff and erosion. Effective management of arid and semi-arid environments requires awareness of the interdependencies of hydrologic, biogeochemical and ecological processes, and collaboration between ecologists and hydrologists. Newman et al. (2006) suggests establishing a monitoring network in a water-limited environment to facilitate this collaboration, from the experimental design phase, through interpretation and modeling.

Much still needs to be learned about the ecological and hydrological interactions on ephemeral and intermittent streams due to variability and the often highly episodic occurrence of extreme events in these systems (e.g. sediment storage and flushing over decadal time scales). There are unique challenges for work on these desert rivers. Sometimes the environments are inhospitable, but arguably the greatest challenge is trying to use short-term projects to understand dryland rivers whose variable behavior sometimes demands years of data more than is needed on a mesic river. As noted, ephemeral and intermittent streams constitute the vast majority of drainage ways in the southwest and they play an integral role in overall watershed function. Future research is needed for both the long-term monitoring of these systems over a range of conditions, and on developing modeling tools that can be applied to large temporal and spatial scales.

References

Babcock, H.M. and E.M. Cushing. 1942. Recharge to groundwater from floods in a typical desert wash, Pinal County, Arizona. Transaction of the American Geophysical Union 23, 49-55.

Baillie, M.N., J.F. Hogan, B. Ekwurzel, A.K. Wahi, and C.J Eastoe. 2007. Quantifying water sources to a semiarid riparian ecosystem, San Pedro River, Arizona, J. Geophysical Res., 112, GO3S02, doi:10.1029/2006JG000263.

Barnett, L.O., R.H. Hawkins, and D.P. Guertin. 2002. Reconnaissance Watershed and Hydrologic Analysis on the Upper Agua Fria Watershed. School of Renewable Natural Resources, University of Arizona, Tucson, Arizona.

Brooks, P.D. and M.M. Lemon. 2007. Spatial variability in dissolved organic matter and inorganic nitrogen concentrations in a semiarid stream, San Pedro River, Arizona, Journal of Geophysical Res., 112, G03S05, doi:10.1029/2006JG000262.

Bull, L.J., and M.J. Kirkby. 2002. Dryland river characteristics and concepts. *In* Dryland Rivers: Hydrology and Geomorphology of Semi-Arid Channels. L.J. Bull and M.J. Kirkby, eds., John Wiley & Sons Ltd., Chichester, p. 3-15.

Bull, W.B. 1997. Discontinuous Ephemeral Streams. Geomorphology 19 (1997) 227-276.

BLM (Bureau of Land Management). 1998. Riparian Area Management: Process for Assessing Proper Functioning Condition. Technical Reference 1737-9.

Costa, J.E. 1987. Hydraulics and basin morphology of the largest flash floods in the conterminous United States. Journal of Hydrology 93:313-338.

Cummins, K.W. and M.A. Wilzbach. 2005. The inadequacy of the fish bearing criterion for stream management. Aquatic Sciences 67(4):486 491.

Del Rosario, R.B. and Resh, V.H. 2000. Invertebrates in Intermittent and Perennial Streams: Is the Hyporheic Zone a Refuge from Drying? Journal of the North American Benthological Society, Vol. 19, No. 4. pp. 680-696.

Gandolfi, C. and G.B. Bischetti. 1997. Influence of the drainage network identification method on geomorphological properties and hydrological response. Hydrological Processes 11(4): 353-375.

Gochis, D.J., L. Brito-Castillo, W.J. Shuttleworth. 2006. Hydroclimatology of the North American Monsoon region in Northwest Mexico. Journal of Hydrology 316:53-70.

Gomi, T., R.C. Sidle, and J.S. Richardson. 2002. Understanding Processes and Downstream Linkages of Headwater Systems. Bioscience; Vol. 52, no. 10, pp. 905-916.

Goodrich, D.C., L.J. Lane, R.M. Shillito, S.N. Miller, K.H. Syed, D.A. Woolhiser. 1997. Linearity of basin response as a function of scale in a semiarid watershed. Water Resource Res. 33(12):2951-2965.

Graf, W.L. 1988. Fluvial Processes in Dryland Rivers. Springer-Verlag, Berlin.

Grimm, N.B., J.R. Arrowsmith, C. Eisinger, J. Heffernan, D.B. Lewis, A. MacLeod, L. Prashad, W.J. Roach, T. Rychener, and R.W. Scheibley. 2004. Effects of urbanization on nutrient biogeochemistry of arid land streams. Pages 129-146, *In:* R. DeFries, G.P. Asner, and R. Houghton, eds., Ecosystem interactions with land use change. American Geophysical Union.

Hereford, R., R.H. Webb, and C.I. Longpre. 2003. Precipitation history of the Mojave Desert region, 1893-2001. U.S. Geological Survey Fact Sheet 117-03, 4 p.

Jacobson, P.J., K.M. Jacobson, P.L. Angermeier and D.S. Cherry. 2000. Hydrologic influences on soil properties along ephemeral rivers in the Namib Desert. Journal of Arid Environments, 45: 21-34.

Keppel, R.V. and K.G. Renard. 1962. Transmission losses in ephemeral stream beds. Journal of the Hydraulics Division, ASCE, v. 8, n. HY3, p. 59-68.

Knighton, A.D. and G.C. Nanson. 1997. Distinctiveness, diversity and uniqueness in arid zone river systems. *In*: Thomas, D. S. G. (ed.) Arid Zone Geomorphology: processes, form and change in drylands, 2nd edition Wiley, Chichester, pp. 185-203.

Koch, J., P. Brooks, M. Conklin and D. Goodrich. 2006. Nutrient Contributions from an Ephemeral Stream. Poster.

Lane, L. J. 1983. Transmission Losses. *In:* National Engineering Handbook, IV. Hydrology. Washington, D. C., USDA, Soil Conservation Service, 21 pp.

Leitner, L.A. Plant communities of a large arroyo at Punto Cirio, Sonora. Southwestern Naturalist 32:21-28.

Louw, G. and Seely, M. 1982. Ecology of desert organisms. Longman Group Limited, New York. 194 p.

Lovich, J.E. 1996. A Brief Review of the Impacts of Tamarisk, or Saltcedar on Biodiversity in the New World. *In:* Proceedings: Saltcedar Management and Riparian Restoration Workshop. Las Vegas, Nevada, September 17 - 18, 1996

McMahon, T. A. 1979. Hydrological characteristics of arid zones. Hydrology of areas of low precipitation, Proceedings of the Canberra Symposium. IAHS-AISH Publication No. 128, pp. 105-123.

Miller, M.E. 2005. The Structure and Functioning of Dryland Ecosystems – Conceptual Models to Inform Long-Term Ecological Monitoring. U.S. Geological Survey Scientific Investigations Report 2005-5197, 73p.

Miller, S.N., D.P. Guertin, K.H. Syed and D.C. Goodrich. 1999. Using high resolution synthetic aperture radar for terrain mapping: Influences on hydrologic and geomorphic investigations. *In:* D.S. Olsen and L.P. Potyondy (Editors). 1999. Wildland Hydrology. American Water Association, Herndon, Virginia, TPS-99-3. pp. 219-228.

National Wildlife Federation (NWF). Streams. Online fact sheet, http://www.nwf.org/wildlife/pdfs/Streams.pdf, accessed May 22, 2007.

Newman, B.D., B.P. Wilcox, S.R. Archer, D.D. Breshears, C.N. Dahm, C.J. Duffy, N.G. McDowell, F.M. Phillips, B.R. Scanlon and E.R. Vivoni. 2006. Ecohydrology of water-limited environments: A scientific vision. Water Resources Research, Vol. 42.

North, C. Drylands Rivers Research, website (last updated Feb. 16, 2005). University of Aberdeen, Scotland. http://www.abdn.ac.uk/~gmi196/DrylandRivers/

Ohmart, R.D. and C.D. Zisner. 1993. Functions and Values of Riparian Habitat to Wildlife in Arizona, A Literature Review. Center for Environmental Studies, Arizona State University, Tempe, Arizona. Submitted to Arizona Game and Fish Department, Contract Number G300-25B.

Pima County. 2000. Biological Stress Assessment, An Overview Discussion of Issues and Concerns. Sonoran Desert Conservation Plan Website, Reports. http://www.co.pima.az.us/cmo/sdcp/reports/d9/008BIO.PDF

Reid, I. and L.E. Frostick. 1989. Channel form, flows and sediments in deserts. Chapter 6 in "Arid Zone Geomorphology", D.S.G. Thomas (ed.), Belhaven Press, London. p. 117-135.

Reid, I. and L.E. Frostick. 1997. Channel form, flows and sediments in deserts. *In*: Arid Zone Geomorphology: Process, Form, and Change in Drylands, D.S.G. Thomas (ed.), Wiley, Chichester, p. 205-229.

Renard, K.G. 1970. The hydrology of semi-arid rangeland watersheds. U.S. Dept. of Agriculture, Agricultural Research Service. Pub. #ARS 41-162.

Richardson, J.S., R.E. Bilby and C.A. Bondar. 2005. Organic matter dynamics in small streams of the Pacific Northwest. Journal of the American Water Resources Association 41(4):921-934.

Rodier, J.A. 1985. Aspects of arid zone hydrology. *In:* Facets of Hydrology, Volume ii, J.C. Rodda. Wiley, Chichester, pp. 205-247.

Rosen, P.C. and Lowe, C.H. 1996. Ecology of the Amphibians and Reptiles at Organ Pipe Cactus National Monument, Arizona. Tech. Report #53. Cooperative Park Studies Unit, The University of Arizona, Tucson.

Scott, S.H. 2006. Predicting sediment transport dynamics in ephemeral channels: A review of literature. Army Engineer Waterways Experiment Station, Vicksburg, MS, Coastal Hydraulics Lab, Report Number: ERDC/CHL-CHETN-VII-6, 9 p.

Sharp, A. L. and K.E. Saxton. 1962. Transmission losses in a mature stream valley. Journal of the Hydraulic Division, Proceedings of the American Society of Civil Engineers, 88, 121-142.

Skagen, S.K., C.P. Melcher, W.H. Howe, and F.L. Knopf. 1998. Comparative Use of Riparian Corridors and Oases by Migrating Birds in Southeastern Arizona. Conservation Biology 12:896-909

Stromberg, J. C. (2001). Restoration of riparian vegetation in the south-western USA: importance of flow regimes and fluvial dynamism. Journal of Arid Environments, 49: 17-34.

Tooth, S. and G.C. Nanson. 2000. The role of vegetation in the formation of anabranching channels in an ephemeral river, Northern plains, arid central Australia. Hydrological Processes, 14, 3099-3117.

Thornes, J.B., 1994, Catchment and channel hydrology. *In:* A.D. Abrahams and A.J. Parsons (Eds.), Geomorphology of Desert Environments. Chapman and Hall, London, p. 257-287.

U.S. Department of Agriculture (USDA), Forest Service. 2002. Management and Techniques for Riparian Restoration, Roads Field Guide, Vol. 1. General Technical Report RMRS-GTR-1-2, vol. 1. Rocky Mountain Research Station, Fort Collins, CO.

U.S. Environmental Protection Agency (EPA). Letter from Benjamin H. Grumbles, Assistant Administrator, EPA, to Ms. Jeanne Christie, Executive Director, Association of State Wetland Managers, dated Jan. 9, 2005.

U.S. Fish & Wildlife Services (USFWS). 1993. Riparian Issue Paper: Lack of Federal Section 404 Clean Water Act Protection of Riparian Areas in the Arid and Semi-Arid Southwest. Arizona Ecological Services Office, U.S. Fish & Wildlife Service.

U.S. Geological Survey (USGS). 2006. National Hydrography Dataset website, http://nhd.usgs.gov/index.html.

Valett, H.M., M.A. Baker, J.A. Morrice, C.S. Crawford, M.C. Molles, Jr., C.N. Dahn, D.L. Moyer, J.R. Thibault, L.M. Ellis. 2006. Biogeochemical and metabolic responses to the flood pulse in a semiarid floodplain. Ecology, 86(1), pp. 220-234.

Ward, J.S. and Associates. 1973. Environmental Protection Study, Pantano Wash, South Tucson and Canada del Oro Areas, Tucson, Arizona. For the Pima Association of Governments. 119 p.

Whitford, W.G. 2002. Ecology of Desert Systems. Academic Press, San Diego, CA. 343 p.

Williams, D.D. 2006. The Biology of Temporary Waters. Oxford University Press, UK. 337 p.

Spatial Scale and the Management of Threatened/Rare/Endangered Species

Michael L. Rosenzweig, Alliance for Reconciliation Ecology University of Arizona

Introduction

No ecologist would blink an eye were someone to point out that environments exist at different scales of space. We can recognize small relatively homogeneous patches of uniform habitat; collections of such patches into ecosystems; sets of ecosystems that form landscapes; and sets of landscapes that merge into an ecoregion. In fact, if two larger spatial scales were added - the whole ecosphere and its component biogeographical provinces -- all of us would nod in agreement, although we would not be entirely sure precisely how to define each of those spatial scales.

This white paper will not attempt to provide such precise definitions. Rather it will concentrate on some of the different processes and problems that operate at different spatial scales. These processes and problems we may define readily and precisely (although I did not think it necessary to do here). Then we may ask how processes at different scales interact and whether knowledge of such interaction promises to help us manage threatened, endangered, and rare species. Notice that some scientists assume the problem of scale to be that of finding unifying mathematical theories which describe phenomena at many scales with the same model. I do not. Whereas such theories certainly exist for some properties (e.g., Enquist, Tiffney & Niklas, 2007; Price & Enquist, 2006; West, 1997) others are so scale dependent that different processes reign at each scale.

Scale can be quantitative or qualitative. I have divided this white paper into two sections corresponding to those classes of scale issues. Some obvious examples of quantitative scale issues:

- Species need minimum areas in which to feed and breed; perhaps most do.
- Some process rates change with area. For example, fire frequency. Because fires spread, especially in fire-climax habitats, the whole area acts as a collector of fires (Sousa, 1984). Small isolated areas will rarely burn compared to small areas ensconced in a large expanse of the same habitat (e.g., Glitzenstein, Streng & Wade, 2003).
- Qualitative differences are often those of multiple habitats. Multiple habitats may incorporate processes at the inter-ecosystem level, processes that are not easy to identify and may not even exist within a single ecosystem.
- A simple example is seasonal migration (more below).
- Another is pressure on threatened species from sink populations of common species (more below).

Some Quantitative Issues: Assessment and Monitoring

Faced with limited resources, managers must often be satisfied with small samples. Samples obtained at a small scale present three problems: a small fraction of individuals are seen; a small fraction of species are recorded; a small fraction of habitats are investigated (Rosenzweig, 2004). At each of these small scales, statistical artifacts may interfere with assessment and monitoring. Raw data may mislead.

Partial censuses: Techniques for dealing with partial censuses have a long history in wildlife management and continue to improve. Two quite powerful ones depend on using data from a sequence of small samples:

the jackknife (Burnham & Overton, 1979) and a series of estimators by Anne Chao and her colleagues (Chao, 1984; Chao, 1987; Chao & Lee, 1992; Chao, Lee & Jeng, 1992; Lee & Chao, 1994).

The jackknife was originally designed to address the issue of partial censuses. Software can be obtained to produce population estimates with it. Note however that jackknife estimates exist for five different orders. Each succeeding higher order separates the data into more bins. First order separates only those individuals that have occurred exactly once; second order also separates those that have occurred exactly twice; etc. whereas specifying a single order of the jackknife and then sticking with it might sound consistent, it will not produce optimal estimates of population size. Burnham and Overton (Burnham & Overton, 1979) did publish a method for choosing among the orders, but most software packages require the user to specify a single order in advance. The exception, WS2M (Turner, Leitner & Rosenzweig, 2000), was designed to estimate the number of species and would require great care were it to be used to estimate the number of individuals.

Anne Chao's most recent efforts (Chao, Yip & Lin, 1996) also stem from the need for good population estimates. But again, software that uses her method (EstimateS: http://viceroy.eeb.uconn.edu/estimates) is designed to estimate the number of species. It seems clear that we have an opportunity and a need here. We need software packages to estimate population size that parallel those designed to estimate the number of species. The math is already published. One serious candidate that should be tried is CARE (Chao et al., 2001).

Estimates of species diversity based on small samples: Small samples impose a negative bias on one's estimate of how many species exist in any finite area (Fisher, Corbet & Williams, 1943). Fortunately, this problem has attracted the sustained attention of first-rate quantitative theoreticians (e.g., Efron & Thisted, 1976). Their theory has resulted in some practical software applications (Chazdon et al., 1998). Every manager tasked with assessing the diversity of a place would be well advised to obtain them, to invest a bit of time in mastering them, and to use them by default.

Many methods do not seem to work very well, which means they do not return reasonable estimates of actual diversities from limited samples. I will not dwell on them here but turn instead to those that should attract the attention of managers. They fall into three groups: comparison indices; extrapolation indices; and indices based on the relative frequency in a sample of individuals that belong to scarce species.

Fisher's α, the only comparison index one needs. In the same paper in which Fisher introduced us to the bias of small samples, he derived a powerful index to address it (Fisher et al., 1943). Mathematically, he divides the number of species in a sample into two moieties; one that depends on the number of individuals in the sample; the other that depends on the number of species from which the sample was drawn. The latter is Fisher's α.

Fisher's α is merely an index of diversity. It does not report the number of species and that is what makes it a comparison index. It should not be converted backwards into a number of species. But it is an index that one can confidently use to compare systems from time to time, and to compare systems to each other. The manager might want to detect a decline in diversity for example. Tracking Fisher's α will enable regression statistics to do that job. Or the manager might wish to compare different treatments or habitats. Applying Fisher's α to replicates will allow one to evaluate such effects.

Extrapolation indices: As sample size grows, more and more species are detected. The result is an accumulation curve (number of species vs. sample size). Extrapolation indices try to fit that curve statistically using a model that has an asymptote (Rosenzweig et al., 2003). The value of the asymptote is

the estimate of the actual number of species. Extrapolation indices are empirical; no theory yet tells us that any of them will be useful.

The oldest extrapolation model is the Michaelis-Menton equation (Holdridge et al., 1971). However if the data occur in the form of actual number of individuals in the sample, then M-M has a bias: all accumulation curves must pass through the point (1,1) but M-M does not. This bias seems to disappear or become unimportant if data occur as presence/absence of each species and ignore actual abundances (Rosenzweig et al., 2003).

A new and promising set of formulae lacks the bias of the Michaelis-Menton equation. One of them, uniquely, has two parameters of curvature. The second parameter allows fitting data sets that have reached (or nearly reached) an asymptote. But if the accumulation curve is still climbing at a good pace, a one-parameter model appears to yield a more accurate extrapolation of the asymptote (Rosenzweig et al., 2003).

Other indices: Jackknife indices and Chao indices look at the pattern of scarcer species in the data. From this, they estimate the number so scarce that they remain undetected. There are five basic jackknife indices as well as a composite based on them. The developers of the jackknife estimators meant us to use only the composite index.

There are six Chao indices but they occur in a developmental sequence that suggests a clear choice among them. The oldest two (often called Chao-1 & Chao-2) were made obsolete by the next two (ACE, the Abundance Coverage Estimator, and ICE, the Incidence Coverage Estimator). ICE relies on presence/absence data alone. The most recent pair is probably even better (Chao et al., 1996). In addition, it produces meaningful confidence intervals. (Meaningful: the true value of S lies between I1 and I2 with 95% certainty. Meaningless: given the nature of the sample, the method would return a value between I1 and I2 in 95% of cases.) But the newest indices are not generally available in software. Watch for them.

The bias reducing estimators of true *S* may be calculated using one of two software packages, *EstimateS* (Colwell, 2004) and *WS2M* (Turner et al., 2000). The former has many advantages. It is well maintained (http://viceroy.eeb.uconn.edu/estimates) and very popular. It can be used on a Macintosh or a WIntel machine. And it is less fussy about data input format. But although the features of the two packages overlap greatly, each does things the other does not. And they are both free. In addition, a bit of wrestling with the options of *WS2M* will help the manager better understand what is really going on and how unresolved is the issue of which estimator is best. Personally, I use three: the composite jackknife (in *WS2M* only); F5 (in *WS2M* only); and *ACE* or *ICE* depending on whether data occur as abundances or presence/absence. (I will adopt the new Chao estimators as soon as I master the newest version of Estimate S or as soon as the version of *WS2M* that has them is released by Wade Leitner.) When all three report a similar value, my own personal tests indicate I should trust it.

Minimum Viable Population (MVP)

As a species' population size declines, theory predicts that the probability of that species' becoming extinct should increase. Certainly every extinct species has passed from some level of abundance to zero. But conservation biologists want to use the concept across species, categorizing common ones as more likely to survive, rare ones as of most concern (e.g., Soulé, 1987). Moreover, they even suggest that a species may face a threshold (its MVP) such that if it drops below a certain population size, it is doomed, and further efforts on its behalf would be a waste of precious resources. More commonly they base their notion of MVP on an arbitrary cutoff point of survival time (e.g., Soulé et al., 1986 decided that a scarce small-medium mammal species with an extinction likely in 200 years or less has less than its MVP).

If these ideas are well founded, they would have considerable consequences for the manager. They suggest a need to keep a close eye on population sizes for one thing, sounding an alarm on behalf of small ones and perhaps even a call to abandon any that seem to have dipped below their MVP. We all know of innumerable cases of the former, of course. But so far I know of no species that has been abandoned as hopeless because of a population that has been calculated to be less than its MVP!

So what do we really know about MVP?

Allee Effects: This is the well founded case. Some species reproduce, or compete, or defend themselves from predation (*sensu lato)* with decreasing success as they become fairly scarce (Allee Effects). If a species is subject to an Allee Effect (for any reason), it may well be that its average per capita rate of reproduction falls below zero if its population declines below a certain value. That value without any doubt would be a well defined M\TP. Notice that Allee Effects may or may not produce an M\TP. There is an M\TP if and only if an N exists below which dynamics are captured by the point N=0. (See Figure 1.)

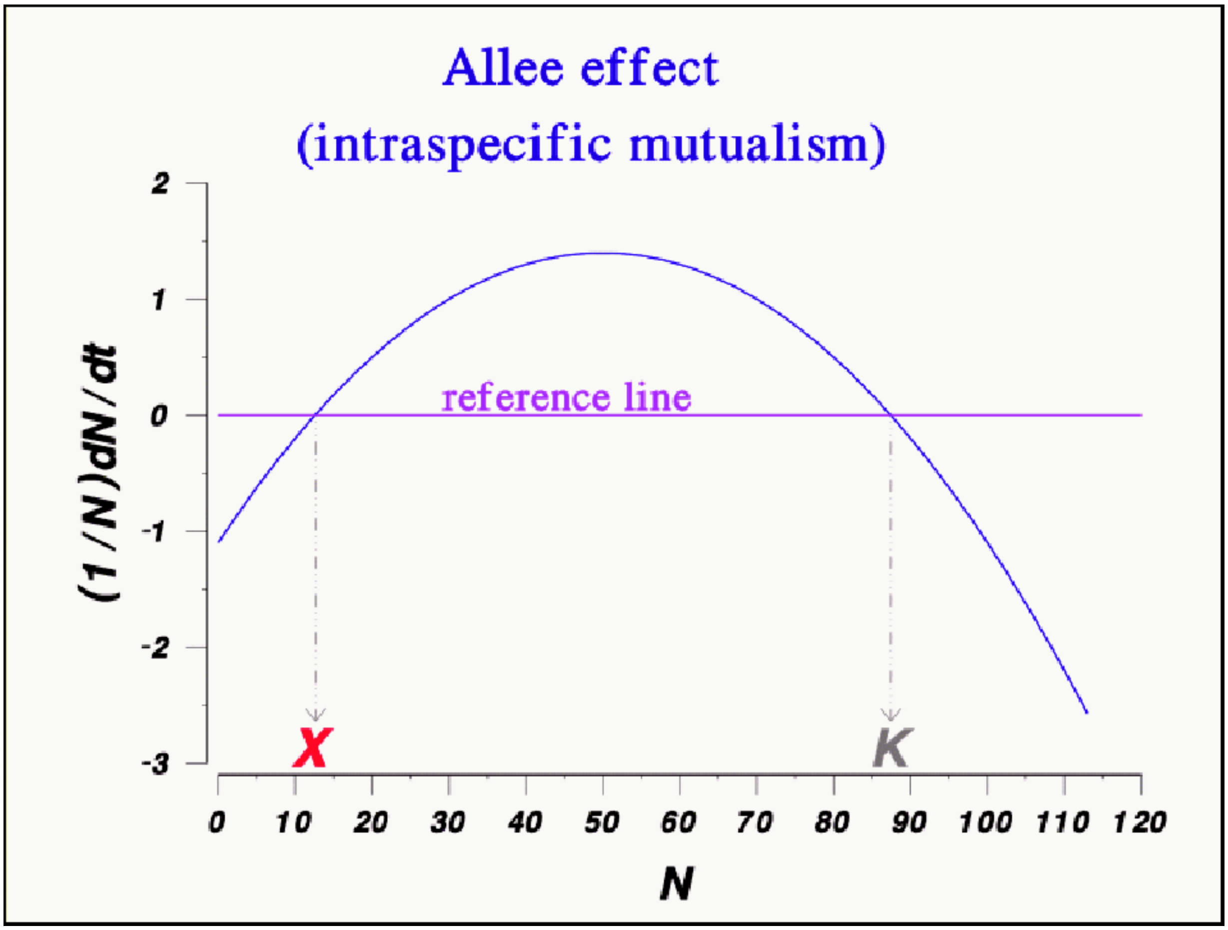


Figure 1. When population size falls below *X,* it is caught by dynamics that lead to extinction. So, *X* is its minimum viable population.

In other cases, we have relied on various mathematical models that produce *N*-dependent extinction probabilities. I will not reiterate them because they are easy to find in the literature, and because I have seen a sophisticated and careful (albeit unpublished) mathematical analysis that calls them all into question (Wade Leitner, personal communication). Leitner believes that accepted models overstate extinction rates

associated with low *N* because they take no account of the improvements in individual circumstances that often accompany scarcity. (There tend to be more resources per capita when a population declines.)

So instead of math, I will stress the empirical side. And empirical results do suggest that managers may profitably turn most of their attention away from the concept of M\TP. Two kinds of evidence imply such a conclusion: meta-analyses and natural history.

Meta-analyses: M\TP does not succeed at identifying TER-species. Traill et al. (2007) conducted a meta-analysis of M\TP estimates of 212 species and found that "a species' or population's M\TP is context-specific, and there are no simple short-cuts to its derivation." Using threat correlates such as body mass and range decline, they also tried to relate M\TP to extinction vulnerability. Even though the threat correlates explain more than 50% of the variation in IUCN threat status, they do not correlate with M\TP.

Rodriguez-Estrella et al. (2006) also obtained that result. Using long-term time-series data, they simulated population dynamics and predicted the M\TP of 1198 species. (Their criterion was 90% probability of persistence over 100 years.) They conclude: "Factors commonly cited as correlating with extinction risk failed to predict M\TP but were able to predict successfully the probability of World Conservation Union Listing. M\TPs were most strongly related to local environmental variation rather than a species' intrinsic ecological and life history attributes."

Natural history: The concept of the minimum viable population sounds logical (and in fact must be true when populations become minuscule, say 10 individuals (Thomas, 1990). But evidence suggests that very tiny populations can persist for thousands of years. Many species are chronically rare.

Edmunds (1982) worked on mayfly species each restricted to a tiny population (no more than hundreds) in a single Utah canyon. He told me they had lived thus at least since the end of the Wisconsin Glaciation (personal communication). The late E. Lendell Cockrum studied voles in small Mexican oases in northern Chihuahua. Oases are surrounded by Chihuahuan Desert. Like the dragonflies, the voles have been isolated since the end of the Pleistocene, and he estimated their populations in the hundreds (personal communication). And the various species of pupfish isolated in local tanks in the desert show inter-tank genetic differences that, whether they satisfy the criteria to call them separate species, do suggest that these tiny populations have been present a long time. Rarity per se would not appear to be a sentence of doom.

Some rare species even have lasted long enough to have adaptations to their rarity. Consider Pima pineapple cactus, *Coryphantha scheeri,* an obligate outcrosser with very short-lived flowers that is restricted to rocky habitat between 700m and 1 500m elevation in a tiny terrestrial box (70km × 80km) in Arizona and Sonora (Roller, 1996). It averages fewer than one plant per four acres per sq km in its geographical range and depends on bee pollinators (McDonald & McPherson, 2005). Without some adaptation to this persistent extreme rarity, one can easily imagine a rapid decline to extinction. Most individuals would flower and fail to set seed. The adaptation that allows the species to survive is straightforward. Its flower buds develop in the spring, but remain dormant until several days after the onset of the summer monsoonal rains. Thus, virtually all individuals flower on the same day.

Henriksen (1997) argues against a focus on "magic numbers," i.e., the MVP of any single species. He pleads for us to understand "the habitat and biology of the interacting species" so as to "allow conservation scientists to make a good estimate of what must be done to save the system," instead of "simply focusing on the numbers that would constitute an MVP of any one interactant." And Rodriguez-Estrella et al. (2006) point out that "the large variation in MVP across species is unrelated to (or at least dwarfed by) the anthropogenic threats that drive the global biodiversity crisis by causing once-abundant species to decline." In the words of Chris Thomas (1990), "Many populations become extinct because the environment changes

in a deterministic way." In sharp contrast, except for MVPs caused by Allee Effects, MVP is a stochastic notion.

What are managers to do about population size? First learn whether the species actually do exhibit an Allee Effect that could entail an undisputed MVP. Then watch these and other populations for signs of persistent decline. Chronic rarity may not be a problem, but the transition from abundance to rarity surely signals a threat. Finally be aware of habitat reduction beyond the area managed. Finally, if at all possible, work with neighbors to extend supportive habitat.

The Need for Standardized Species-Area Relationships (SPARs)

As the scale of a sampling area grows, it contains more and more species. Such patterns are termed 'species-area relationships' (SPARs). Within an ecoregion, SPARs indicate that habitat heterogeneity grows with area. Or else they are a statistical artifact, merely indicating that as larger areas are studied, more individuals are recorded. Careful application of the methods of the section about bias-reducing estimators of S will prune the artifacts from the real biology and leave the manager with the underlying signal of habitat heterogeneity.

Species-area relationships have been known since the early nineteenth century. Having studied them that long, ecologists are able to claim that SPARs show certain regular, repeated patterns. *They can usually be fit with an Arrhenius equation of the form $\log S = c + z\log A$, where S is number of species; A is area; c and z are constants to be determined by regression. *The constant c varies from taxon to taxon and from place to place. It does not however vary with area. So c-values provide an appropriate measure of species density. (Note that because z is generally different from 1.00, one cannot measure species density as S/A.)

*The constant z on the other hand varies very little when measured for different taxa within a single ecoregion. Whether we look at shrub species in the Chihuahuan Desert or bird species in Ohio, or ants in Connecticut, z does not vary much above or below 0.15. A good rule of thumb: expect it to be between 0.1 and 0.2.

The properties of SPARs present an opportunity to develop natural standards for species density. Once we have them, managers will be able to compare them to the species densities of the places that they manage. With experience, we should be able to interpret such comparisons and develop forecasts from them.

I find it surprising to realize that we do not yet have very many standard SPARs, not even for charismatic flora and fauna such as wildflowers, butterflies, birds and fishes. We need to remedy that for four or five taxa in the nation's 100+ ecoregions. The Heinz Center, as part of its long term effort to develop environmental indicators for the nation, is working in that direction (The H. John Heinz III Center for Science Economics and the Environment, 2002). Meanwhile the local manager can develop and use them locally. In the absence of adequate amounts of natural open space, managers can go outside the fences for the required data. It may be obtained with a small number of replicate, nested sampling areas, and need not be obtained more than once for each taxon of interest.

Source-Sink Dynamics

Although they continue to be present every year, some of the populations inside DoD fences may not be sustainable. These populations are called sink populations (Shmida & Ellner, 1984). They occur continually because individuals disperse into them fairly regularly, making up for any shortfall in local reproduction and survival. In contrast, populations that do sustain themselves locally are called source populations.

Sink populations present managers with two questions. Managers need to determine whether a particular species in their bailiwick is failing dynamically. And they need to have a system sense of the proportion of such species in their list.

Answering the first question takes a combination of careful natural history and demographic studies. I know no shortcuts. Being moderately expensive, such work must be concentrated in the few species of special interest on a DoD range. Prioritization demands careful dialog between managers and many outside influences (including the US Fish & Wildlife Service, conservation NGOs and the public at large).

McGill and Collins (2003) suggest a simple and powerful method to estimate the answer to the larger, system question. The key lies in comparing SPARs at two scales, the SPARs measured within a continental ecoregion, and those measured in archipelagos (island SPARs).

The species list of a whole island contains no sink species because dispersal to them is relatively rare (Rosenzweig, 1995). It is so rare in fact that we call it immigration. While waiting for immigrants, any potential sink species on an island will become extinct. Therefore island species must sustain their presence with adequate net reproductive rates.

Because island lists lack sink species, they have fewer species than a mainland counterpart area of the same size and set of environments. Thus the extra species of a mainland area represent the collection of sink species. We do not know exactly which species these are, but we can calculate their number by simple subtraction.

When McGill and Collins (2003) compared the diversity of birds from mainlands with those from islands, they arrived at astonishingly high estimates of the proportion of sink species in small local areas (from standard breeding bird surveys). Fewer than half, perhaps as little as a quarter of the species in the average BBS route, were source populations.

Identifying the proportion of sink populations will accomplish two things. It will serve notice that DoD ranges cannot be held responsible for all species that they contain. And it will encourage managers to look at the larger scale, encouraging joint undertakings with neighbors whose land lies beyond the fences.

Some Qualitative Issues: Pressure On Threatened Species from Populations of Common Species

Population interactions may depress the population size of prey and of competitors. We certainly know that predation can lead to extinction e.g., (Carlton et al., 1991; Merkel, 1906; Pimm, 1987). And we suspect that competition may as well (Moulton & Pimm, 1987; Rosenzweig, 1995). This issue becomes a matter of scale as soon as we realize that some of those negative interactions may arise from species that thrive in nearby habitats.

Perhaps the threat comes from a common species with a broad realized niche, i.e., one that pays but a small reproductive/survival price for not living in its very best habitat. Or perhaps the threat comes from a common species whose source populations exist in other habitats, but whose exuberant dispersal allows it to maintain a substantial sink population in a habitat that is crucial to a species of concern. (Please recall that the largest, most dense populations of a species may be their sink populations — Keddy, 1981.)

Lovejoy and his colleagues (Ferraz et al., 2007) pioneered the research into sink populations that reduce the value of protected habitats. Some bird species require mature tropical forest. But patches of forest that might support them become less valuable to the extent that their geometry allows them to be penetrated and exploited by individuals of common species that depend on other habitats for their existence. In his

experiments, Lovejoy concentrated on the geometry (i.e., perimeter to area ratios). But once we realize what a high proportion of bird populations are sink populations, we appreciate that the question he discovered promises to be much more general than geometry.

Assuming the interactive threat comes from a species limited to the same habitat as the species of concern, the manager may have little choice but to let nature take its course. However, if the threat does come from a sink population or from a habitat-tolerant species, intervention could be considered. Some managers have already had to face this question.

An outstandingly difficult case arose in Channel Islands National Park. It is the sole home of a species of grey fox (*Urocyon littoralis)* with different subspecies on a number of the separate larger islands. A century ago, agricultural interests decided that bald eagles were too likely to kill their young stock animals (lambs and piglets). They extirpated the bald eagle from the islands.

After a number of decades, golden eagles discovered the Channel Islands and established a nesting population. Unlike the piscivorous bald eagle, golden eagles do eat mammals. They lived on piglets and such. In seasons when agricultural prey were scarce, they switched to Channel Island foxes (Roemer et al., 2001). Soon *Urocyon littoralis* was decimated. It became extinct on two of the islands and was in a death spiral on a third. Captive populations were banked against the day the species would disappear from the wild (The Nature Conservancy, 2003b).

The obvious answer (from the conservationist's perspective) was to eliminate the golden eagle population in the park and replace it with a bald eagle population to defend against future invasion by golden eagles. But the golden eagle is also protected. So the obvious answer took years to decide upon and carry out (Roemer & Donlan, 2004). The fox is again successful (The Nature Conservancy, 2003a; The Nature Conservancy, 2003c).

Problems with larger predators may be easier to detect then problems with small competitors. Managers need to expand their scale of thinking beyond individual species even to recognize them. Thinking about and researching and managing communities of organisms may not expand spatial scale but it does expand another kind of scale up to the level of the natural community. And, as I have suggested, if something untoward is going on in a natural community, appreciating the spatial scale of the multi-habitat ecoregion may provide a framework that could help take care of it.

<u>Seasonal Migration</u>

Many taxa of conservation importance contain species that migrate seasonally. Certainly winged taxa — birds, bats and butterflies — head the list. But many quadrupedal mammals also migrate — heroically so in Africa, although less prominently in North America (perhaps because of the Pleistocene mass extinction?). Migrations may be dramatic covering thousands of kilometers. Or they may be quite local, some species merely changing elevation with the seasons. But all migrants are using multiple habitats during the year. All remind us of the futility of restricting our efforts to a single habitat when trying to care for species' futures.

Besides raising consciousness, one is hard pressed to add very much to the obvious advice: pay attention to which species do migrate and try to take the environmental pulse of places they visit annually to see whether your efforts might best be directed towards problems in those venues. And reach out to managers in other states and nations whose responsibilities to their migrants may depend on your management practices. Even in this age of heightened homeland security concerns, I hope the DoD can find ways to allow that openness.

Yet, perhaps there is something else to add. Migration is dangerous business. Passage migrants and winter visitors may not be on your list of breeders but they may utterly depend on your management skills. In southeastern Arizona, the sandhill crane, which winters in the Wilcox Playa each year, is a prominent example. But another, a foreign example, reveals the extraordinary potential value of paying attention to the needs of migrant species, especially in arid ecoregions.

One of the three principal flyways used by birds to move from Europe and western Asia to Africa cuts through the southernmost tip of Israel in the city of Eilat. Hundreds of species use it, about one billion birds per passage. There is a very good reason. Eilat had a saltmarsh that once extended over a $12km^2$ area. Having traveled non-stop for hundreds of km over barren desert, the birds could find food and shelter there (Yosef, 1996).

But Eilat's saltmarsh has vanished, plowed and bulldozed by construction for a massive resort district. Just before the last square kilometer disappeared, Reuven Yosef, director of Eilat's International Bird Observatory, managed to have an abandoned landfill reconfigured into an artificial saltmarsh. To compensate for the 92% decrease in area, Yosef raised the productivity several-fold with irrigation and even non-native plant species. The result? Whatever losses of population and diversity might have occurred, have been averted.

<u>Climate Change</u>

Habitats are rooted in appropriate climates. As climates change, the habitats of any spot will also change. Some species can handle the new climatic realities of a place. Some can track climate changes by shifting their ranges (e.g., Coope, 1987). And some will be left in the heat or the wet or the newly dry.

We can do very little for the last group except remove them to zoos, hoping to re-introduce them to a saner world when the time comes. And the first group needs no help. But the middle group ought to become a focus of attention. We need to identify them before they attain TES status. We need to discover whether they will be able to relocate gradually on their own, or will need to have their populations artificially restarted some distance away. One should recall that a substantial proportion of plant species did not successfully move north as glaciers retreated at the end of the Wisconsin (Davis, 1983; Davis, 1986).

Of course, needing to allow species to move suggests that we need to increase our wildlife corridors. And that is correct. But the scale at which we think about corridors is adjusted to problems different from those caused by climate change. It is a rather local scale, designed to permit small scale seasonal migration or to ameliorate fragmentation by linking areas set aside for nature. Those goals have their value (although fragmentation's effect on overall diversity remains debatable – (Fahrig, 2003; Harrison & Bruna, 1999; Yaacobi, Ziv & Rosenzweig, 2007).

But the scale of corridor required to allow re-siting of whole species' ranges is another matter. It may never as yet have been attempted.

One of the lessons we learn from considering climate change will be important to the next topic also. Just because, at the scale of her responsibilities, a manager has no control over a phenomenon does not mean that phenomenon should be ignored. It will likely impact local scales and require local action.

The Impending Mass Extinction

In this section I will explore the roots and magnitude of the mass extinction we fear. You will learn that currently accepted estimates of extinction are far too small. You will also learn that no species is safe. But stopping the mass extinction is do-able and DoD is now a leader in this effort as we shall see.

Why we worry: Nature is retreating. Habitat has been converted to human use leaving many species without appropriate homes. It is just that simple. Or is it?

Our response to the problem has been reservation ecology: keep as large a variety of habitats as possible available for nature by setting them aside, by keeping our mitts off! This has worked fairly well to slow down extinction rates.

But what of the long term? How sustainable is diversity if we set 10% of the land aside? Or 20%. The world's answer to this question has been a 20% goal. Why?

As we reviewed above, larger areas harbor more species. The pattern of that relationship, the species-area relationship (SPAR), can be fit with a log-log model. Noticing that reserves geographically resemble islands, conservationists were inspired to use the SPARs of island biogeography theory to make their predictions.

Archipelagic SPARs have a lot of curvature. (Their z-values are typically about 0.30.) Curvature means that as area increases, additional area units suffer diminishing returns, tending toward a plateau, at least in appearance. It is that curvature which reassured the policy makers at Rio. If we manage 20% of the land for nature, they reasoned, we will avert almost all of the mass extinction. Unfortunately, there are serious problems with that hope.

The first problem is climate change. Every species depends on at least one habitat and habitats depend on their climate. With natural habitats restricted to isolates, a change of climate will represent a loss of habitat for an unknown fraction of the species in it (see climate change section above). That will impose a higher rate of extinction on the isolated reserves and a loss of some of their species. Even as psuedo-islands, the properties of their system dynamics will suffer.

However the 20% recipe decided on at Rio relies on island biogeography theory and that makes it untenable because isolated reserves are not even psuedo-islands. SPARs (area patterns) have different causes at different scales (Rosenzweig, 2003a). The island scale depends on the process of immigration to supply new species and immigrants come from a mainland with a fixed species pool. But although mainlands as a system are drained by extinction like islands, mainlands add species via speciation — a much slower process than immigration. So the truth is that our system of reserves are bits of mainland. Meanwhile, the mainland species pool is not fixed as in island biogeography theory. Because the mainland is suffering substantial loss of natural area, the pool of species it can sustain has declined substantially.

Well, at least speciation/extinction systems are sustainable (whereas island systems, relying as they do on an outside donor of species are not). But their sustainable species diversity is well below the (nonsustainable) diversity of a similar-sized island. So the loss of diversity caused by restricting nature to isolates will be far worse than that envisioned by the Rio conference. How much worse? As Rio imagined, the answer lies in the SPARs.

SPARs of mainlands (i.e., biogeographical provinces) are much straighter than those of islands. Their known z-values range from about 0.60 to 1.00 (Rosenzweig, 1995). They are skewed toward the larger of those numbers, and a value of unity is an easy one to find in the data and to think about. A value of unity means linearity of the SPAR when plotted on ordinary arithmetic axes (as opposed to linear axes). Thus,

if we want to forecast the species diversity of a taxon with a z-value of unity, we can approximate the math in our heads.

A taxon with a z-value of unity will keep 10% of its species if we set 10% of the land aside. Or 20% if we set 20% aside. The end result of relying on the 20% value targeted by Rio will be a mass extinction that takes 80% of species (Rosenzweig, 2005). The situation is not quite as dire for taxa with z-values near 0.6, but a SPAR with that value still has very little curvature compared to an archipelagic SPAR. In short, we need somehow to supplement those set asides if we are to prevent a mass extinction.

Implications of large-scale SPARs: With so much to accomplish and so meager a budget, the manager could be forgiven for trying to discern a set of species in trouble and letting the rest fend for themselves. However the large scale SPAR tells us that our science does not support such a strategy. Since nature has already lost an immense proportion of area (some say estimate 40%; some 95%), no species is safe. We cannot identify the species we will lose, and trying to do so may be like trying to identify the water molecules that will boil off as we make our coffee. Based on system properties and processes, we can predict the fraction that will evaporate but not which ones!

So all the species of a military range are potential TE-species. They are embedded in a larger scale system whose shrunken state implies a great deal of current trouble at that larger scale and promises a great deal of future trouble at all smaller scales. What can the manager do?

Reconciliation ecology: Ultimately, making all the land available for nature is the only scale that will allow restoration of the same sustainable diversity level as existed before Western civilization. In order to approach this ideal, our reserve system will need to partner with people at many scales of human organization, scales such as military reserves that utilize very large areas of land for human purposes as well as the much smaller scales of neighborhood associations, backyards and schoolyards.

The large area of land required cannot be removed from the treasury of land on which people rely; it will continue to be used. Instead we need to discover ways that allow it to support wild native species. We *reconcile* our uses with those of nature, hence the strategy is called *reconciliation ecology* (Rosenzweig, 2003b). Formally defined, reconciliation ecology means "inventing, establishing and maintaining new habitats to conserve species diversity where people live, work and play."

Notice that the scale of the effort to conserve species diversity is not specified. It could mean locally only. But it could also mean enlisting a local site in a more widespread effort to conserve diversity at a larger scale and coordinating what is done at that site with the needs of conservation at the larger scale.

Notice also the difference from other forms of landscape greening. Add some trees or grass, and most people would say, fine, mission accomplished. But the reconciliation ecology project demands the targeting of a specific list of species for preservation. It requires the discovery and deployment of new habitats designed to allow those species to thrive — to live and reproduce successfully. It is not concerned with attracting those species but with giving them a theater in which they can achieve the status of source populations. Thus, reconciliation ecology demands a lot of pre-deployment research: natural history research, behavioral ecology research and community ecology research. It requires the skills and dedication of the professional manager.

The DoD is already a world leader in reconciliation ecology. In many of its installations it has accomplished the research and deployed exciting new habitats that often so closely mimic the old ones as to be confused for restoration ecology. (Restoration ecology adds to our set-asides — Jordan, 2003.) The army at Ft. Hood TX; the Marines at MB Camp Pendleton CA; the Air Force at Eglin AFB FL; the National Guard at Ft. Indiantown Gap Military Reservation PA; and many, many other installations keep watch over the

species of some 29 million acres as well as watch the defense of this nation. They do not do it by accident. They do it by carefully coordinating the needs of wild species with those of the branch of the military that they serve.

The reconciliation knowledge and skills that DoD managers acquire can be shared with neighbors to help them improve diversity on their own properties. Because all species must be considered at risk until we reconcile a considerable amount of land, installations can accomplish considerable good for diversity by targeting species that are currently of no concern. Then they can help other landowners do the same. They do not have to invite landowners to target species that are currently on a watch list. In the long run, such reconciliation will lift a good bit of the conservation burden from DoD. It will prevent many species from ever being considered rare, threatened or endangered. And it will cease being responsible for the only good populations of so many native species.

Literature Cited

Burnham, K. P. and Overton, W. S. (1979). Robust estimation of population size when capture probabilities vary among animals. *Ecology* **60,** 927-936.

Carlton, J. T., Vermeij, G. J., Lindberg, D. R., Carlton, D. A. & Dudley, E. C. (1991). The first historical extinction of a marine invertebrate in an ocean basin: the demise of the eelgrass limpet. *Biol. Bulletin* **180,** 72-80.

Chao, A. (1984). Non-parametric estimation of the number of classes in a population. *Scandinavian J. Statistics* **11,** 265-270.

Chao, A. (1987). Estimating the population size for capture-recapture data with unequal catchability. *Biometrics* **43,** 783-791.

Chao, A. & Lee, S.-M. (1992). Estimating the number of classes via sample coverage. *J. Amer. Statistical Assoc.* **87,** 210-217.

Chao, A., Lee, S.-M. & Jeng, S.-L. (1992). Estimating population size for capture-recapture data when capture probabilities vary by time and individual animal. *Biometrics* **48,** 201-216.

Chao, A., Tsay, P. K., Lin, S. H., Shau, W. Y. & Chao, D. Y. (2001). The applications of capture-recapture models to epidemiological data. *Statistics in Medicine* **20,** 3123-3157.

Chao, A., Yip, P. & Lin, H. S. (1996). Estimating the number of species via a martingale estimating function. *Statistica Sinica* **6,** 403-418.

Chazdon, R. L., Colwell, R. K., Denslow, J. S. & Guariguata, M. R. (1998). Statistical methods for estimating species richness of woody regeneration in primary and secondary rain forests of northeastern Costa Rica. In *Forest biodiversity research, monitoring and modeling: Conceptual background and Old World case studies,* vol. 20. *Man and the Biosphere* (ed. F. Dallmeier and J. A. Comiskey), pp. 285-309. UNESCO & the Parthenon Publication Group, Paris and New York.

Colwell, R. K. (2004). *EstimateS: Statistical estimation of species richness and shared species from samples, version 7.* http://viceroy.eeb.uconn.edu/EstimateS.

Coope, G. R. (1987). The response of late Quaternary insect communities to sudden climatic changes. In *Organization of Communities Past and Present* (ed. J. H. R. Gee and P. S. Giller), pp. 421-438. Blackwell Scientific, Oxford.

Davis, M. (1986). Climatic instability, time lags, and community dis-equilibrium. In *Community Ecology* (ed. J. Diamond and T. Case), pp. 269-284. Harper and Row, New York.

Davis, M. B. (1983). Holocene vegetational history of the eastern United States. In *Late-Quaternary Environments of the United States* (ed. H. E. Wright, Jr.), pp. 166-181. Univ. of Minnesota Press, Minneapolis.

Edmunds, G. F. (1982). Historical and Life-History Factors in the Biogeography of Mayflies. *American Zoologist* **22,** 37 1-374.

Efron, B. & Thisted, R. (1976). Estimating the number of unseen species: how many words did Shakespeare know? *Biometrika* **63,** 35-41.

Enquist, B. J., Tiffney, B. H. & Niklas, K. J. (2007). Metabolic scaling and the evolutionary dynamics of plant size, form, and diversity: toward a synthesis of ecology, evolution, and paleontology. *Int. J. Plant Sci.* **168,** 729–749.

Fahrig, L. (2003). Effects of habitat fragmentation on biodiversity. *Annual Review of Ecology, Evolution and Systematics* **34,** 487-5 15.

Ferraz, G., Nichols, J. D., Hines, J. E., Stouffer, P. C., Bierregaard, R. O. & Lovejoy, T.E. (2007). A large-scale deforestation experiment: Effects of patch area and isolation on Amazon birds. *Science* **315,** 238-241.

Fisher, R. A., Corbet, A. S. & Williams, C. B. (1943). The relation between the number of species and the number of individuals in a random sample of an animal population. *J. Animal Ecology* **12,** 42-5 8.

Glitzenstein, J. S., Streng, D. R. & Wade, D. D. (2003). Fire frequency effects on longleaf pine (*Pinus palustris* P. Miller) vegetation in South Carolina and northeast Florida, USA. *Natural Areas Journal* **23,** 22-37.

Harrison, S. & Bruna, E. (1999). Habitat fragmentation and large-scale conservation: what do we know for sure? *Ecography* **22,** 225-232.

Henriksen, G. (1997). A scientific examination and critique of minimum viable population size. *Fauna Norvegica, Serie A* **18,** 33-41.

Holdridge, L. R., Grenke, W. C., Hatheway, W. H., Liang, T. & Tosi, J. A. (1971). *Forest environments in tropical life zones.* Pergamon Press, Oxford, UK.

Jordan, W. R., III. (2003). *The Sunflower Forest; Ecological restoration and the new communion with nature.* University of California Press, Berkeley, CA.

Keddy, P. A. (1981). Experimental demography of the sand-dune annual, *Cakile edentula,* growing along an environmental gradient in Nova Scotia. *J. Ecology* **69,** 615-630.

Lee, S.-M. & Chao, A. (1994). Estimating population size via sample coverage for closed capture-recapture models. *Biometrics* **50,** 88-97.

Mcdonald, C. J. & Mcpherson, G. R. (2005). Pollination of pima pineapple cactus (*Coryphantha scheeri* var. *robustispina*):does pollen flow limit abundance of this endangered species? *USDA Forest Service Proceedings* **RMRS-P-36,** 529-532.

Mcgill, B. & Collins, C. (2003). A unified theory for macroecology based on spatial patterns of abundance. *Evolutionary Ecology Research* **5,** 469-492.

Merkel, H. W. (1906). A deadly fungus on the American chestnut. *N. V. Zoological Society Ann. Report* **10,** 97-103.

Moulton, M. P. & Pimm, S. L. (1987). Morphological assortment in introduced Hawaiian passerines. *Evolutionary Ecol.* **1,** 113-124.

Pimm, S. L. (1987). The snake that ate Guam. *Trends in Ecology and Evolution* **2,** 293-295.

Price, C. A. & Enquist, B. J. (2006). Scaling of mass and morphology in plants with minimal branching: an extension of the WBE model. *Int. J. Plant Sci.* **20,** 11–20.

Rodriguez-Estrella, R., Carmen, M. & Moreno, B. (2006). Rare, fragile species, small populations, and the dilemma of collections. *Biodiversity and Conservation* **15,** 162 1-1625.

Roemer, G. W., Coonan, T. J., Garcelon, D. K., Bascompte, J. & Laughrin, L. (2001). Feral pigs facilitate hyperpredation by golden eagles and indirectly cause the decline of the island fox. *Animal Conservation* **4,** 307-318.

Roemer, G. W. & Donlan, C. J. (2004). Biology, policy and law in endangered species conservation: I. The case history of the island fox on the northern Channel Islands. *Endangered Species Update* **21,** 23-31.

Roller, P. S. (1996). Distribution, growth, and reproduction of Pima pineapple cactus (*Coryphantha scheeri* Kuntz var.*robustispina* Schott), University of Arizona.

Rosenzweig, M. L. (1995). *Species diversity in space and time.* Cambridge University Press, Cambridge, UK.

Rosenzweig, M. L. (2003a). Reconciliation ecology and the future of species diversity. *Oryx* **37,** 194-205.

Rosenzweig, M. L. (2003b). *Win-win ecology: How the Earth's species can survive in the midst of human enterprise.* Oxford University Press, New York.

Rosenzweig, M. L. (2004). Applying species-area relationships to the conservation of species diversity. In *Frontiers of biogeography; New directions in the geography of nature* (ed. M. V. Lomolino and L. Heany), pp. 325-343. Sinauer Associates, Sunderland, MA.

Rosenzweig, M. L. (2005). Avoiding mass extinction: basic and applied challenges. *American Midland Naturalist* **153,** 195-208.

Rosenzweig, M. L., Turner, W. R., Cox, J. G. & Ricketts, T. H. (2003). Estimating diversity in unsampled habitats of a biogeographical province. *Conservation Biology* **17,** 864–874.

Shmida, A. & Ellner, S. (1984). Coexistence of plant species with similar niches. *Vegetatio* **58,** 29-55.

Soulé, M. E. (1987). Viable Populations for Conservation. Cambridge U, Cambridge.

Soulé, M. E., Gilpin, M., Conway, W. & Foose, T. (1986). The millennium ark: How long a voyage, how many staterooms, how many passengers? *Zoo Biology* **5,** 101-113.

Sousa, W. P. (1984). The role of disturbance in natural communities. *Annual Review of Ecology and Systematics* **15,** 353-391.

The H. John Heinz III Center for Science Economics and the Environment. (2002). *The State of the Nation's Ecosystems.* Cambridge University Press, Cambridge.

The Nature Conservancy. (2003a). Santa Cruz Island: Bringing Back the Bald Eagle. 3.

The Nature Conservancy. (2003b). Santa Cruz Island: Foxes, Pigs, and Eagles. 1.

The Nature Conservancy. (2003c). Santa Cruz Island: Relocating Golden Eagles. 2.

Thomas, C. D. (1990). What do real population dynamics tell us about minimum viable population sizes? *Conservation Biology* **4.**

Turner, W., Leitner, W. A. & Rosenzweig, M. L. (2000). *Ws2m.exe,* http://eebweb.arizona.edu/diversity.

West, G. B., Brown, J.H. & B.J.Enquist. (1997). A general model for the origin of allometric scaling laws in biology. *Science* **276,** 122-126.

Yaacobi, G., Ziv, Y. & Rosenzweig, M. L. (2007). Habitat fragmentation may not matter to species diversity. *Proc. R. Soc. B* **274,** 2409-2412.

Yosef, R. (1996). An oasis in Elat. *Natural History* **105,** 46-47.

Military Land Use: Overview of DoD Land Use in the Desert Southwest, Including Major Natural Resource Management Challenges

William W. Doe III, Center for Environmental Management of Military Lands, Colorado State University, Fort Collins, CO 80523.

Timothy J. Hayden, U.S. Army Corps of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, Illinois.

Robert M. Lacey, U.S. Army Corps of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, Illinois.

William D. Goran, U.S. Army Corps of Engineers, Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, Illinois.

Abstract

DoD military land use of the desert southwest includes a wide spectrum of military weapons testing, force-on-force training, and various types of flight training. The desert southwest provides a critical asset for the U.S. military — open space. Installations in the desert Southwest tend to be much larger than the installations in other regions of the nation, with several in excess of one million contiguous acres. This open space asset has allowed the military to historically establish large training areas and ranges on installations and to define expansive air maneuver regions above these ranges and above the vast public lands of other agencies. Training and testing activities are conducted in the 3-dimensional land/air space that replicates the modern battle space. Land and air space use is highly variable among installations depending on mission requirements. Overall, the southwest desert region is a critical asset to the U.S. military, in part because it offers critical training and testing areas that are analogs to similar worldwide environments where the military operates. Natural resource management challenges include the large spatial extent of lands and air space under DoD management, highly variable military land use requirements, significant endangered species regulatory and conservation requirements, encroachment and Base Realignment and Closure requirements, competition for water resources and climate change. DoD natural resource managers attempt to meet these challenges through inter-agency cooperative agreements, integrated natural resource management plans, and DoD sustainable range programs.

Introduction: Description of DoD Facilities in the Desert Southwest

Open spaces, often associated with public land holdings, of the Mojave, Sonoran and Chihuahuan Deserts of the southwestern United States (Figure 1, all figures in this paper are adapted from Goran et al., submitted manuscript), provide an important resource in meeting the military's expansive requirements for weapons testing, force-on-force training, and various types of flight training. The focus of this SERDP workshop is on Department of Defense activities and effects on natural resources in three major desert ecoregions; the Mojave Desert, the Sonoran Desert and the Chihuahuan Desert.

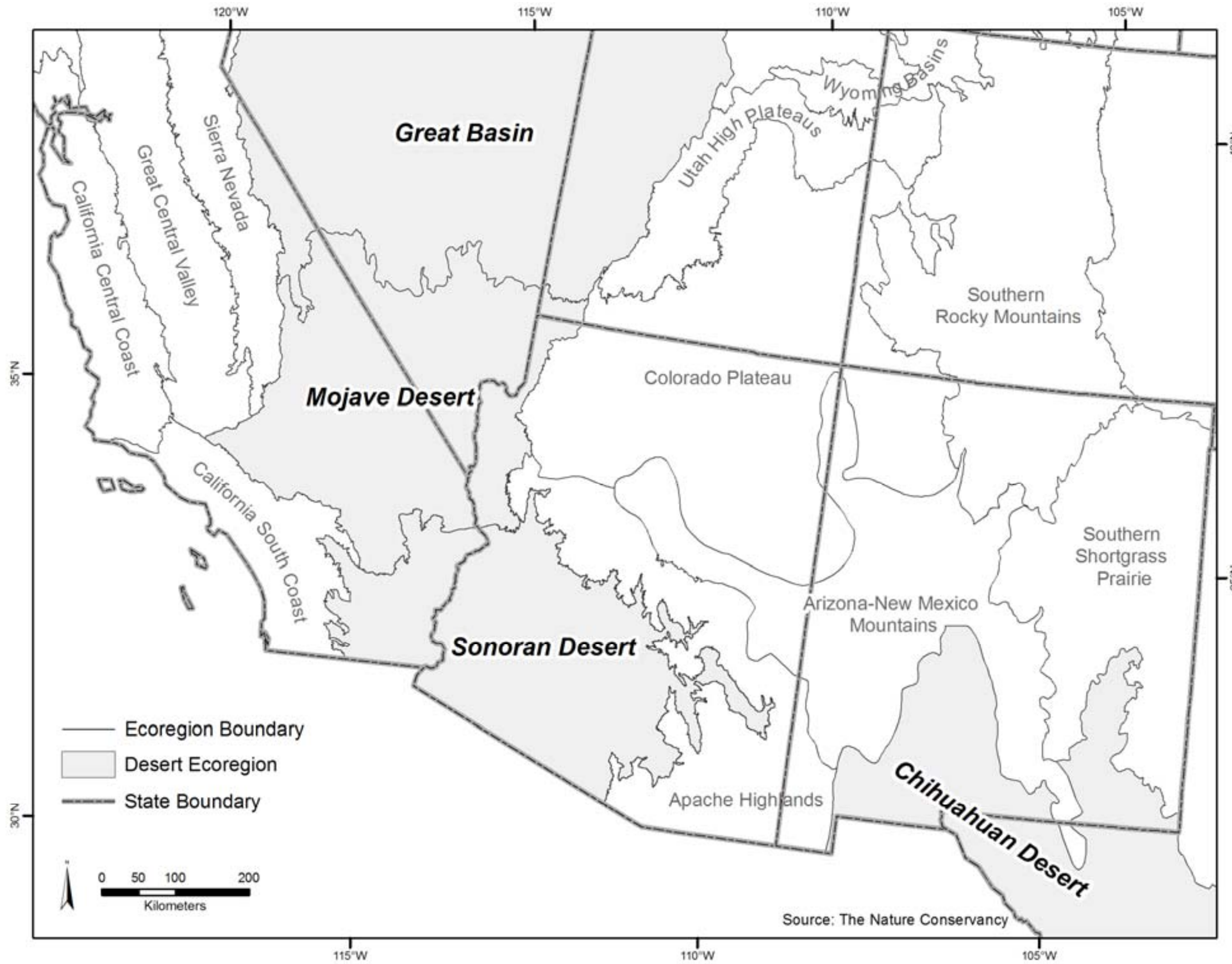


Figure 1. Deserts in the ecoregions of the southwestern United States. The Great Basin is not included in the scope of this workshop. (Ecoregions adapted from Bailey 1995)

Within these three desert ecoregions, federal land holdings occupy approximately 84% of the Mojave Desert, 70% of the Sonoran Desert, and 26% of the Chihuahuan Desert.

Figure 2 illustrates the major Department of Defense holdings in these ecoregions, under the control of the Armed Services – Air Force, Army, Marine Corps and Navy. Within these regions, there are also numerous smaller land holdings including installations supporting the Military Reserves and National Guard such as the Florence Military Reservation and Western Army National Guard Aviation Training Site in Arizona. Major installations in the desert Southwest tend to be much larger than the installations in other regions of the nation, with several in excess of one million contiguous acres. White Sands Missile Range, in south-central New Mexico and the adjoining Fort Bliss, Texas, are the largest installations in the Chihuahuan Desert. In southwestern Arizona, the Barry M. Goldwater Range and Yuma Proving Ground occupy large segments of the Sonoran Desert. The Mojave Desert hosts a complex of military facilities in California, including, from north to south, Naval Air Weapons Station China Lake, the Army's National Training Center at Fort Irwin, Edwards Air Force Base, Marine Corps Air Ground Combat Center at 29 Palms, and the Marine Corps Chocolate Mountains Aerial Bombing and Gunnery Range. Nellis Air Force Base and Range Complex occupies a broad stretch of Nevada just north of Las Vegas within both the Mojave Desert and the Great Basin Ecoregion.

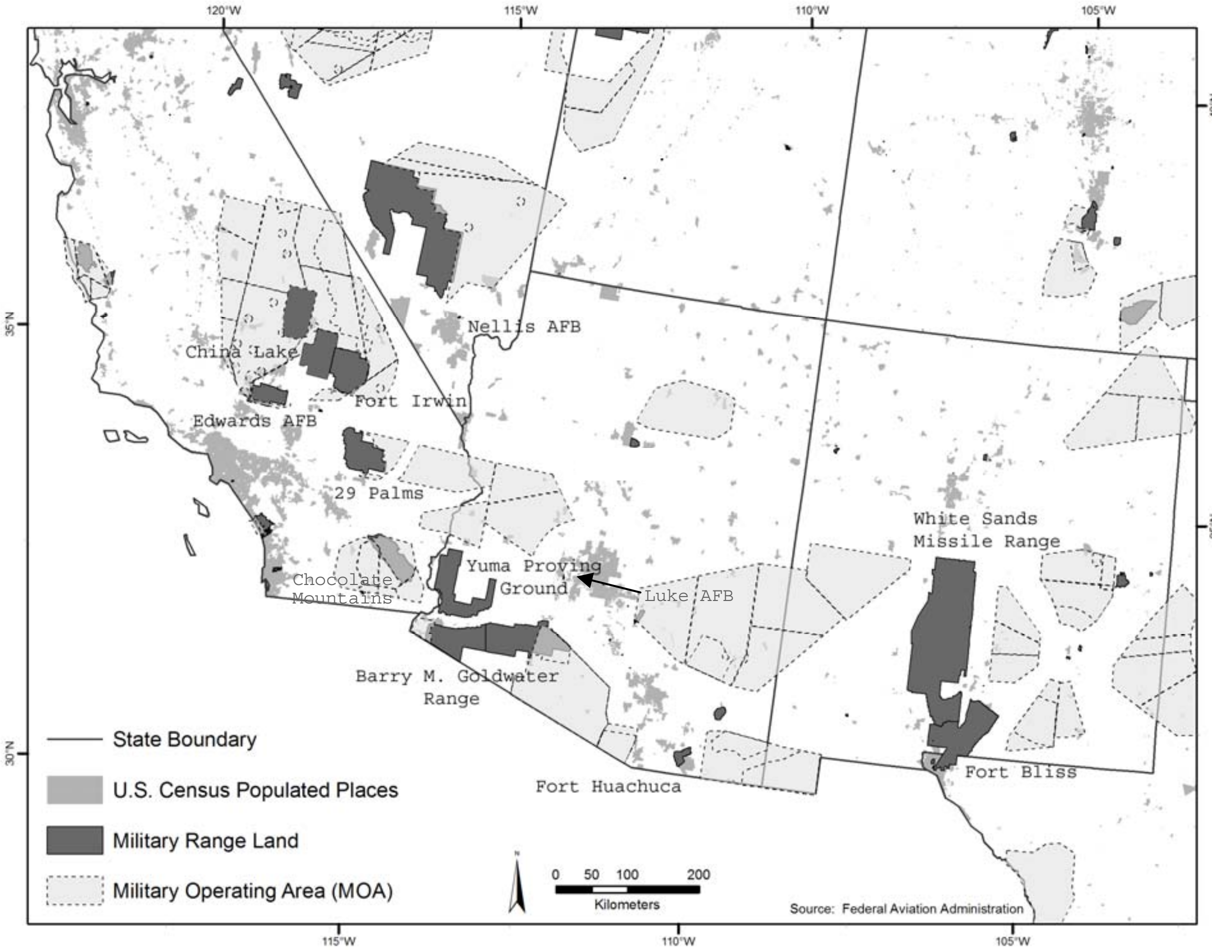


Figure 2. Major military bases in the Mojave, Sonoran and Chihuahuan ecoregions and MOAs for flight operations.

These installations represent only the areas "within the fence line" (land area under military land ownership or control). In the Southwest especially, the military makes use of extensive areas beyond the fence lines. Figure 2 shows the major military bases (dark grey) and military operating areas (light grey) that are provided for flight operations. These military operating areas (MOAs) include a large portion of the skies above the southwestern desert. Figure 3 depicts a region of southern California and Western Arizona, showing four military installations (Marine Corps Air Ground Combat Center at 29 Palms, Chocolate Mountains Aerial Bombing and Gunnery Range, Yuma Proving Ground, and Barry M. Goldwater Range) and their associated military operating areas (shaded light grey). Federal lands are shown as patterned. Within this area and across the southwestern region, a geospatial analysis shows a ratio of more than two public acres for every one private acre under these MOAs.

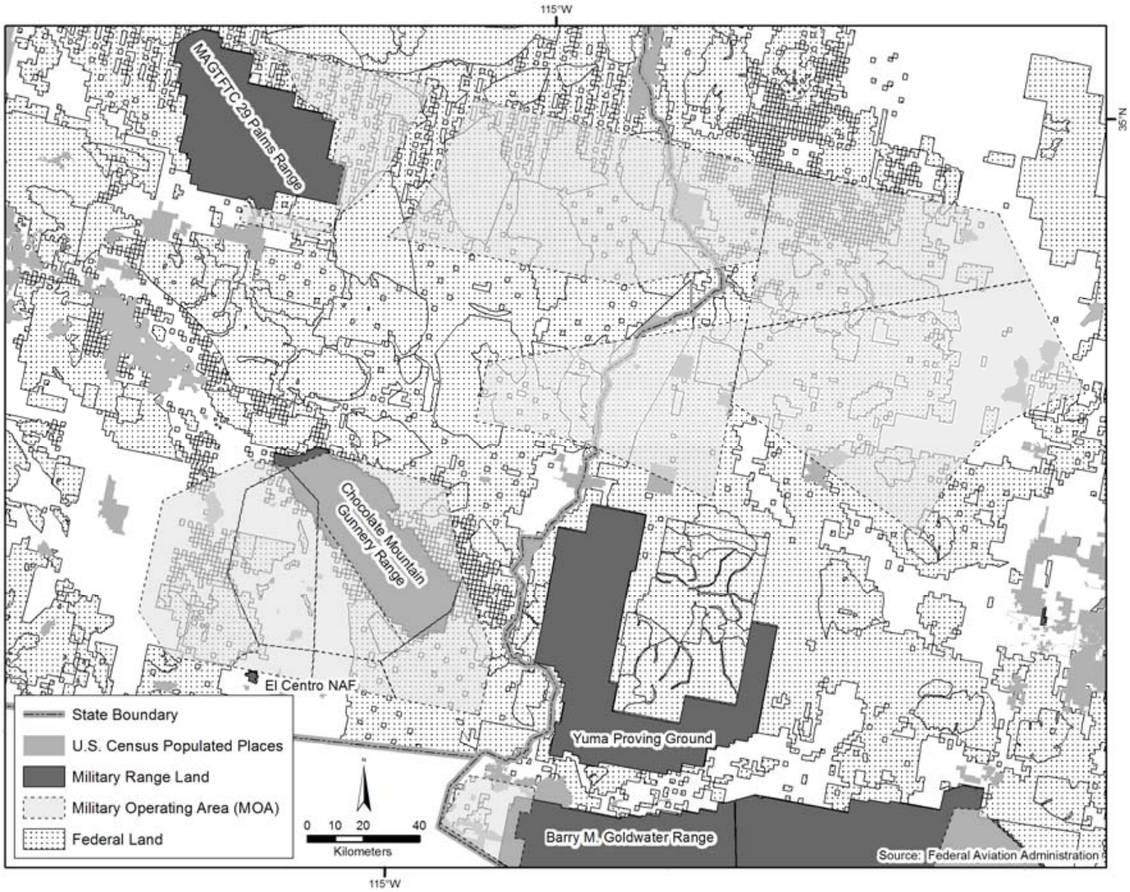


Figure 3. Selected southwestern installations and their MOAs.

Description of DoD Military Land and Airspace Use of Southwestern Deserts

DoD military land use of the desert southwest includes a wide spectrum of military air and land training and testing activities. The desert southwest provides a critical asset for the U.S. military — open space. This open space asset has allowed the military to historically establish large training areas and ranges on installations and to define expansive air maneuver regions above these ranges and above the vast public lands of other agencies. These expansive land and air spaces allow more realistic, major exercises, testing and joint operations. Overall, the southwest desert region is a critical asset to the U.S. military, in part because it offers critical training and testing areas that are analogs to similar worldwide environments where the military operates. Major DoD installations in the desert southwest and service affiliations are listed in Table 1.

Table 1. Major DoD installations, service affiliation and land area in the desert southwest.

Installation	Service	Size (acres)	Primary Mission
Fort Huachuca, AZ	Army	81,311	Training
Yuma Proving Ground, AZ	Army	838,983	Testing
Fort Irwin (National Training Center (NTC), CA	Army	786,680	Training
White Sands Missile Range, NM	Army	2,151,184	Testing
Fort Bliss, TX and McGregor Range, NM	Army	1,037,282	Training
Naval Air Weapons Station China Lake, CA	Navy	1,100,000	Testing
Nellis Air Force Base and Range Complex, NV	Air Force	3,100,000*	Training
Edward's Air Force Base, CA	Air Force	300,723	Testing
Luke Air Force Base, AZ	Air Force	4,359	Training
Marine Corps Air Ground Combat Center, 29 Palms, CA	Marines	596,000	Training
Chocolate Mountains Aerial Bombing & Gunnery Range, CA	Marines	456,000	Training
Barry M. Goldwater Range, AZ	Multi-service	1,700,000	Training

*Includes the Nellis Range complex of which only the southern portions fall within the Mojave Desert Ecoregion.

The following sections provide a brief review by service of the type of military land and air space use in the desert southwest.

Army

The Army's force size and land-based missions require the most land for training and testing activities. Historically, many of the largest Army installations are found in the Southwest. This footprint goes back to the early years of World War II and the former Desert Training Center, where General George S. Patton conducted the first large-scale tank maneuvers in 1941-42 (Bischoff 2000) in preparing forces for armored maneuver combat in the North African and European theaters. This former maneuver area once consisted of 56 million acres along the California and Arizona border. Between 1945 and 1973 unprecedented Congressional investments of over $100 billion into western installations established the Army's present day footprint in the region. Today, of the Army's approximately 11.9 million acres of total operational range space in the United States, approximately 5.2 million acres, or 44%, are located in the desert Southwest. This desert acreage is contained primarily within the five Army installations listed in Table 1.

The continued availability of expansive land and air spaces, relatively distant from population centers, is essential for maneuver training with large forces (Brigade-sized elements of 3,000-5,000 troops and hundreds of tactical vehicles) and testing of long-range weapons systems, unmanned aerial vehicles, and laser/optical systems. By their nature, Army operations in desert environments typically occur over large distances, with limited infrastructure to support troop and logistical movements. Many deserts occupy large terrestrial areas with sparse human settlements and relatively isolated urbanized centers. In addition to longer transportation and movement distances, training doctrine for tactical dispersal of units in desert operations results in increased dependence on long-range weapon systems and radio-communications links, and increased distance in line-of-sight engagements. Furthermore, modern lethal and non-lethal weapons, non-line-of-sight systems, and other systems including lasers and unmanned aerial vehicles, require extensive operating distances. These factors necessitate appropriate land availability and contiguous land configurations, including overhead and adjacent operating airspace, to support training, testing and evaluation. The lack of land availability in other regions of the United States, the Army's infrastructure investment in the region, and the current influx of forces from forward deployed areas back to U.S. installations further amplifies this requirement.

These training and testing needs are even more critical given the ongoing deployment of U.S. forces to desert theaters of operation in Southwest Asia. Desert and steppe (dry) environments represent 32% of the world's continental landmass and encompass many areas of strategic interest. The ability to train forces and test equipment in friendly environments similar to those found abroad (world analogs) is a key component of the Army's "train as we fight" and "natural environments for testing" strategies. Perhaps the most critical aspect of sustaining these desert installations is that they represent the physical environments that are analogous to those found in current (i.e. Iraq and Afghanistan) and other potential Southwest Asia operational theaters. The ability for commanders to train forces under similar desert conditions and for the testing community to assess the performance of weapons systems, materiel, and equipment in this harsh climate is paramount to Army readiness (Shaw et al. 2000).

Navy

The Naval Air Weapons Station China Lake is the primary Navy facility in the desert southwest and is the site where the Navy and Marine Corps have developed or tested nearly every significant airborne weapon system in the past five decades. China Lake supports the primary research, development, test and evaluation work for air warfare and missile weapons systems. China Lake carries out the complete weapon-development process - from basic and applied research through prototype hardware fabrication, test and evaluation, documentation, and Fleet and production support. Missiles such as Sidewinder, Shrike and Walleye are just a few of the many products which have been developed for the Fleet at China Lake.

China Lake, encompasses 1.1 million acres of land in California's upper Mojave Desert, accounting for approximately one-third of the Navy's total land holdings. The land, ranging in altitude from 2,100 to 8,900 feet, varies from flat dry lake beds to rugged piñon pine covered mountains. The majority of the land is undeveloped and provides habitat for more than 340 species of wildlife and 650 plant species.

Air Force

The primary Air Force installations in the desert southwest include Edwards, Luke and Nellis Air Force Bases (Table 1, Figure 2). These bases provide facilities, training and support for the full-spectrum of Air Force aviation training and testing including weapons development and testing, flight training, air-to-air combat training and air-to-ground weapons training. These installations are also responsible for the scheduling and use by other units, such as A-10 squadrons flying from Davis-Monthan Air Force Base near Tucson, of the extensive military operational air spaces throughout the desert southwest.

Edwards Air Force Base consists of approximately 301,000 acres of largely undeveloped or semi-improved land that is used predominantly for aircraft test ranges and maintained and unmaintained landing sites (i.e., dry lake beds). Edwards Air Force Base has two unique natural resources that help make it the premier flight test facility in all the world; Rogers Dry Lakebed and Rosamond Dry Lakebed. Both lakebeds have been used for emergency and test landings of aircraft for more than 40 years, literally saving hundreds of aircrew lives and aircraft valued at millions of dollars because they offer a broad expanse of hardened clay on which to land aircraft in emergency situations. The main Edwards concrete runway is located next to Rogers Dry Lakebed, and combining this runway's 15,000 foot length with a 9,000 foot lakebed overrun, gives pilots with an in-flight emergency one of the longest and safest runways anywhere in the world. Rogers Dry Lake has been used since 1977 as the landing site for many space shuttle test and operational flights. Rogers has a surface of about 28,000 acres with seven "drawn on" runways crisscrossing the surface of Rogers, with the longest extending 7 1/2 miles. Rosamond Dry Lake, several miles southwest of Rogers, offers 13,400 acres of smooth flat surface which is also used for routine flight test and research operations and for emergency landings.

Luke AFB has served as an airfield for more than 50 years acting as the base for a wide range of aircraft from the AT-6 to the F-16. Luke Air Force Base is home to the 56th Fighter Wind and is the largest fighter training base in the western world. The 56th Range Management Office also is responsible for all environmental issues and flight operations associated with the eastern segment of the Barry M. Goldwater Range (See “Multi-service” section, below).

Nellis Air Force Base - "Home of the Fighter Pilot" - is part of the United States Air Force's Air Combat Command. It is home to the largest, most demanding and advanced air combat training in the world. Nellis provides training for composite strike forces which include every type of aircraft in the US Air Force inventory. Training is also conducted in conjunction with air and ground units of the Army, Navy and Marine Corps as well as air forces from allied nations. The main base covers approximately 11,300 acres, 7,000 acres (62 percent) of which are undeveloped. Flight operations originating from Nellis use vast areas of military operational air spaces in the desert southwest for both low- and high-level aviation combat training. Much of this training is conducted over the 3.1 million acre Nellis Range Complex north of Las Vegas. Portions of the Nellis Range Complex extend into the upper Mojave Desert, and Nellis Air Force Base is responsible for management of this range.

Marine Corps

The Marine Corps Air Ground Combat Center at Twenty-nine Palms is the home to the world's largest Marine Corps Base. It is the premier live-fire training facility in the world for Marine operations and draws military personnel from all over the world for Combined Arms Exercises. Each year roughly one-third of the Fleet Marine Force and Marine Reserve units - some 50,000 Marines in all - participate in the base's training exercise program. These training exercises involve every weapons system in the Marine Corps' arsenal, from small arms to attack aircraft. They are absolutely essential to maintaining high levels of readiness required of the U.S. Marine Corps to fight and defend U.S. national interests. The Combat Center at Twenty-nine Palms occupies 596,000 acres of the southern Mojave Desert. Such a sizable land area is essential to the conduct of realistic air/ground combat training exercises.

The Marines Corps also has primary use of the ranges and facilities on the Chocolate Mountains Aerial Bombing and Gunnery Range and approximately 3.2 million acres of airspace designated for military use in California, and the use of ranges and approximately 3.2 million acres of airspace in the western segment of the Barry M. Goldwater Range (see “Multi-service” section, below) in Arizona. The primary purpose of these ranges is to provide full spectrum support for Marine Corps tactical aviation training. The Chocolate Mountains Aerial Bombing and Gunnery Range is an unattended/non-instrumented ordnance range. Marine Corps Air Station Yuma is responsible for scheduling, land management and environmental compliance on the Chocolate Mountains Aerial Bombing and Gunnery Range and portions of the Barry M. Goldwater range administered by the Marine Corps.

Multi-Service

The 1.7 million acre Barry M. Goldwater Range located in southwest Arizona serves the U.S. Air Force, U.S. Marine Corps and “tenant” units of the other services, Reserves and National Guard as an armament and high-hazard testing area; a training area for aerial gunnery, rocketry, electronic warfare, and tactical maneuvering and air support; and a place to develop equipment and tactics. Tactical aviation training occurs in the skies above the Barry M. Goldwater Range, and surface impacts are limited to targets scattered over the tactical and manned ranges. Because these targets have been in the same locations for decades, most of the surrounding land serves as a safety buffer and is not impacted by training activities.

The Barry M. Goldwater Range was established under federal law that “withdrew” public lands for DoD use. This range may be viewed as having two land sections. Luke Air Force Base is the designated

administrator for military activities on the eastern section of the range, with training activity generally confined to the eastern section of the range. The Marine Corps is the primary military manager and user of the western section of the range. Effective in 2001 with the land withdrawal reauthorization, the Marine Corps and Air Force became responsible for natural resource management on the range in coordination with the state and the U.S. Fish and Wildlife Service.

Prior to the 2000 National Defense Authorization Act, Cabaña Pieta National Wildlife Refuge and Wilderness was a component of withdrawn lands for the Barry M. Goldwater Range. The 2000 authorization act rescinded this withdrawal and jurisdiction over the refuge returned to the Department of Interior. All management responsibilities for these lands lie with the U.S. Fish and Wildlife Service.

Challenges for Natural Resources Management on Military Lands

Natural resource management challenges on DoD lands of the southwestern deserts are quite varied as a function of the training and testing activities that an installation supports. All DoD installations must comply with state and federal environmental laws to protect natural resources. The challenge for DoD natural resource managers is meeting natural resource management objectives while minimizing constraints on military mission requirements. The multiple inter-service and inter-agency administrative and management responsibilities on many DoD installations in the desert southwest can further complicate natural resources management, planning and compliance activities.

In order to meet environmental mandates, military installations include many environmental professionals and programs that focus on managing desert lands to ensure environmental stewardship in concert with mission requirements to train and test. These efforts include the development of Integrated Natural Resources Management Plans for each installation. These plans articulate environmental stewardship goals and objectives and identify issues that may conflict with the military mission. In addition to its existing environmental programs the Army has implemented the Sustainable Range Program at these installations to ensure access, availability and capability on live fire ranges to support mission requirements. The Sustainable Range Program incorporates land condition monitoring, rehabilitation and repair of damaged areas and environmental awareness training under the Integrated Training Area Management (ITAM) program. ITAM professionals work closely with the range operations and environmental staffs to sustain the training and testing activities on the installations.

These DoD planning and programming initiatives must address natural resource management challenges across multiple scales including the installation, regional and global levels. The following discussion describes the major natural resources management challenges at each of these scales.

Installation Challenges – Training and Testing Impacts and Endangered Species Compliance

On installations that support major ground maneuver training activities such as Fort Irwin National Training Center and Fort Bliss, direct disturbance has a large footprint on the landscape and presents large scale land management challenges. The environmental impacts of military maneuver training and similar land use activities (e.g., recreational vehicle use of all-terrain vehicles) in desert environments have been well documented (El-Baz and Makharita 1994, Webb and Wilshire, 1983). As one example, the persistence of effects from tracked vehicle disturbances in the Mojave Desert during pre-World War II (1941-42) tank maneuvers has been studied extensively by scientists. Sixty years later, evidence of these effects in terms of soil compaction has been found both at the surface and below the surface (Prose 1985). It is recognized that any intensive maneuver activity in desert environments will have some long-term impacts for soil and vegetation recovery. Much of the long-term impact on desert environments can be attributed to the biological crusts and desert pavements associated with these environments. These crusts and pavements tend to hold the limited soil matrix in place and when damaged can severely disrupt the

micro scale hydrologic conditions and resulting recovery and support of vegetation (Belnap and Warren 2002).

This point is further illustrated by a map of military lands resiliency (Figure 4). The mapping unit boundaries, derived from Bailey's (1995) ecoregional map of the United States, depict the relative "resilience" of lands in the United States based upon rates of soil and vegetation recovery from maneuver-like disturbances (Doe et al. 1999). As illustrated, the desert ecoregions in the Southwest have relatively low resilience to maneuver impacts because water is not available to support soil aeration and hydration and vegetative growth. Conversely, desert lands may have a higher resiliency than other ecoregions to contamination by military munitions and constituents in live fire impact areas, since the lack of water reduces particulate contaminant transport and migration in soils and groundwater (Houston et al. 2001).

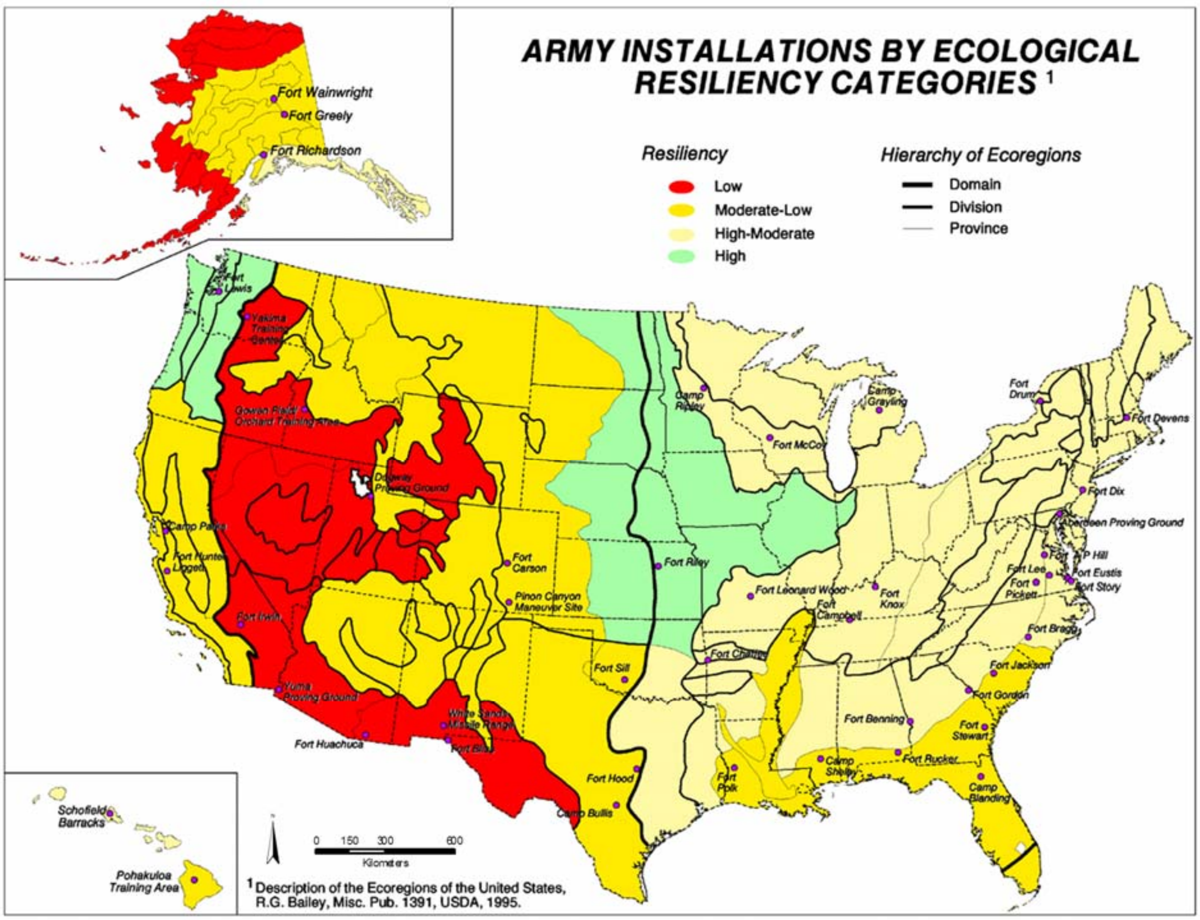


Figure 4. Interpretation of ecological resiliency related to land-disturbing impact. (Adapted from Bailey 1995.)

On installations where weapons testing is the primary mission such as White Sands Missile Range and on aerial bombing and gunnery ranges such as Barry M. Goldwater Range, ground disturbing activities and contamination are relatively localized on designated impact areas and test facilities. These designated impact areas and test facilities represent a relatively small proportion of the total installation land area and typically are surrounded by safety buffer zones that are largely undisturbed. Designated impact areas are

subject to significant and repeated physical disturbance. Weapons components and munitions residue can result in localized, potentially hazardous waste zones, cleanup and maintenance of toxic waste in these areas is problematic because of repeated use and access restrictions due to unexploded ordnance. Effects of aerial overflights have been a concern for several species including the Sonoran pronghorn antelope (*Antilocapra americana*), desert bighorn sheep (*Ovis canadensis nelsoni*) and Mexican spotted owl (*Strix occidentalis lucida*). At the Barry M. Goldwater Range, for example, flight routes were modified to minimize potential effects on the pronghorn. Conservation and compliance requirements for endangered and threatened species on military lands is one of the most significant natural resource management challenges for DoD installations in the desert southwest. According to data compiled by NatureServe and provided on the SERDP Southwest Workshop website, approximately 27 terrestrial and five aquatic species are federally listed on DoD installations in the desert southwest. The number of listed species and the associated demands on military land managers is only likely to increase in the future. Approximately 75 terrestrial and four aquatic species could be considered as "species at risk" and thus potentially eligible for future listing according to data compiled by NatureServe and provided on the SERDP Southwest Workshop website. The presence of endangered species (flora and fauna) can constrain military land use activities where compliance with the Endangered Species Act (ESA) is required. These constraints can include modification of overflight routes, exclusion of ground disturbing activities, and implementation of scheduling limitations or modifications. One example is the desert tortoise (*Gopherus agassizii*), an endangered reptile whose habitat exists in desert environments of the Southwest including several DoD installations. Presence of the desert tortoise on the Fort Irwin National Training Center was a significant issue in the recent land expansion of the installation (National Training Center, 2007). The installation expansion led to a major relocation effort for desert tortoise populations because proposed mechanized maneuver activities within the expansion zone was considered incompatible with continued persistence of desert tortoise in the expansion zone. The Fort Irwin example illustrates that while regulatory compliance for endangered species is the responsibility of the individual agency, solutions to endangered species conservation issues often requires inter-agency and regional collaboration.

The Fort Irwin expansion illustrates many of the land management complexities associated with DoD land withdrawals in the southwest. Many of the major land areas under DoD jurisdiction in the southwest are the result of federal legislative action to "withdraw" lands from public use for national defense purposes. Withdrawn lands include the Barry M. Goldwater Range, Nellis Range Complex, MacGregor Range (part of Fort Bliss), and the expansion lands associated with the National Training Center. Most of these withdrawn lands originally were under the jurisdiction of the Bureau of Land Management. The jurisdictions and management authorities for these withdrawn lands are complex and vary across installations and are subject to individual installation and interagency management plans and memorandums of agreement. In some cases, DoD has primary responsibility for natural resources management (e.g. Barry M. Goldwater Range) and in some cases the Bureau of Land Management has primary responsibility (e.g. MacGregror Range). A further complication is that DoD land withdrawals are subject to renewal. The 1986 legislation had a 15-year term. The renewal actions under the 2000 National Defense Authorization Act wer complex, and sometimes controversial, and require ongoing collaboration and interaction among several federal, state and local government agencies. These complexities are likely to be revisited when the 25-year term for withdrawals under the 2000 Act expire.

<u>Regional Challenges – Demographic Trends and Water Resources</u>

Although urban and agricultural encroachment of desert southwest installations is relatively less than for installations located in more populated areas of the United States, current and future trends anticipate increased population growth in the desert southwest with associated pressures on military training activities on adjacent DoD lands and competition for limited resources, particularly water. The land uses in the southwestern desert regions have changed in recent history, with increases in agricultural use on

private land holdings, and, especially in the last half of the 20th century, significant increases in urban and suburban land uses. Nabhan and Plotkin (1994) state:

> "Since World War II, the 'Sunbelt' - including the Sonoran Desert and adjacent biomes - has suffered from the greatest in-migration and most massive land conversion occurring within any fifty-year period in human history. Within the last half century, the number of human inhabitants in the region has increased seven-fold... "

External population pressures are exacerbated by present-day realignment and transformation of Army forces from forward basing in Europe and Korea back to the United States, the DoD's Base Realignment and Closure (BRAC) process and the Integrated Global Presence and Basing Strategy (IGPBS) will result in significant influxes of Brigade-sized elements to installations in the desert Southwest. For example, four Army Brigade Combat Teams (BCT), have been designated for stationing at Fort Bliss, TX over the next five years, with an expected increase of 30,000 soldiers and 20,000 civilians and military dependents (U.S. Army, Oct 2006).

Increasing populations in the desert southwest because of increased urbanization and base realignment activities, is resulting in significant regional competition for limited water resources. The water supply issue poses considerable concern for military activity and land management in the desert southwest—the military is one of many competing stakeholders for limited water resources. U.S. Geological Survey reports that since the 1960s there have been several feet of subsidence in the Las Vegas Valley and "land subsidence is projected to continue as a function of ground water withdrawals" (Acevedo et al. 2003). However, the Las Vegas Valley population has been among the fastest growing in the United States and is projected to continue rapid population increases, and increased surface water withdrawal will place this community in competition with other surface water users in the region (e.g., Southern California and Central Arizona). Leake et al. (2000) report ground water levels dropping more than 200 feet in some areas, especially in Sonoran basins in Arizona. They also report significant subsidence in Arizona, California and Nevada, primarily due to slow drainage of water from the clay and silt sediments in our near to aquifers (Leake et al., 2000).

Recently, controversial legislative actions (e.g. the Renzi rider to the 2004 Defense Appropriations Bill) and civil lawsuits have focused on water use by Fort Huachuca and surrounding urban areas and the effects of ground water depletion on the San Pedro River and associated endangered species. At issue for DoD is the relative responsibility of military installations to mitigate for ground water depletion by non-military activities off the installation.

Fort Bliss has collaborated with the City of El Paso in implementing desalination technologies for brackish groundwater—this investment was one of the factors that convinced the Army to station more units at the base. Troop stationing decisions, such as those related to BRAC, take into account the current and likely future availability of water resources at different bases.

Because installations in the southwest are typically surrounded by predominantly public land holdings and sparsely populated private lands, these regional issues highlight the need for cooperative agreements among diverse federal, state and local agencies. Regional cooperative efforts, such as the Mojave Desert Initiative and the Sonoran Desert Initiative, have been undertaken by the DoD in concert with state and federal agencies and non-governmental entities to protect and conserve natural resources of the desert Southwest. These collaborative initiatives provide a foundation for addressing other regional environmental issues and resource concerns that transcend the "fence lines" between military and non-military spaces. However, cooperative efforts can also create significant challenges based on the relative roles and responsibilities of government land management agencies with diverse responsibilities and land management objectives.

Global Challenges - Climate Change

Continued population increase, climate change and/or extended drought cycles will exacerbate future conflicts for limited water resources and other resource values. Measured weather trends show a consistent rise in temperatures and an increase in extreme rainfall events, especially at lower elevations. But these patterns differ by major basin, as well as by elevation within the basins. Multiple years of below-normal rainfall for the region as a whole, however, would cause increased conflicts between stakeholders for allocation of water resources.

Climate change will also present regulatory and natural resources challenges for DoD land managers. How will land managers respond in a regulatory framework that is based on the ability manage and mitigate effects due to local and regional processes, when changes in population distribution and abundance may be caused by global processes? How will land managers be able to differentiate between causal processes at local, regional and global scales? Changes in population abundance and distribution because of global processes will challenge a regulatory framework that is based on the ability to manage and mitigate effects that are due to local or regional processes.

Summary

Summary of Military Training Activities on DoD Installations in the Desert Southwest

- Desert southwest installations support the full range of military training and testing activities, including air-to-air combat, aerial gunnery and bombing, mechanized ground maneuver, artillery live-fire and direct-fire weapons ranges.
- Training and testing activities are conducted in the 3-dimensional land/air space replication the modern battle space.
- DoD utilizes land and air spaces beyond the installation fence-line.
- Land and air space use is highly variable among installations depending on mission requirements.

Summary of DoD Natural Resources Management Challenges in the Desert Southwest

- Natural resources mitigation and management options are constrained by low resilience and climate extremes associated with the desert southwest ecosystems.
- Endangered species conservation and management responsibilities are significant and are likely to increase with future population growth and climate change.
- Increasing urbanization in combination with increased use of military facilities resulting from BRAC actions and global repositioning of forces will increase demands for air and land space use and particularly limited water resources.
- Climate trends affecting species distribution and abundance will challenge compliance activities under current regulatory frameworks.
- Status of withdrawn lands requires complex inter-agency collaboration for natural resources management responsibilities and jurisdiction.
- The scale of the land and air space of DoD installations creates demands on personnel and management costs.

Recommendations

The following recommendations are a composite of the views of the paper's authors. These recommendations do not reflect official DoD, service or agency policy. The purpose of these recommendations is to stimulate an exchange of ideas among workshop participants on the priorities and best approaches for meeting the significant natural resource management challenges facing land management agencies in the desert southwest today and in the future.

1. Promote and enhance inter-agency collaboration conservation initiatives for TES and other at-risk natural resources. Regional natural resource management objectives should be identified to reduce inter-agency conflict and competition for management resources that result from different land management priorities, objectives and jurisdictions among agencies.
2. Develop enhanced monitoring and modeling capabilities to assess the relative contribution of local, regional and global processes to ecosystem risk. Optimal use of limited land management resources can only be accomplished by understanding which natural resources states and trends are amenable to management intervention.
3. Support increased technology development, implementation and policies for water conservation and re-use. Inter-agency conflict over water resources will continue to increase in the future without a significant technology and policy push for water use efficiency.
4. Develop a regional, DoD inter-service strategy for future military land requirements. Optimal use of available and future land and air space for military training and testing will require the services to coordinate land acquisition, withdrawals, and development of buffer zones with a common ecological-based understanding of landscapes and the potential impacts of military use.
5. Address potential regulatory compliance issues related to global population and climate trends. The environmental regulatory framework developed in the 20^{th} century may not provide adequate flexibility and mechanisms to address future population and climate trends of this century.
6. Continue DoD development and implementation of "green" alternatives for ammunition, explosives and other ordnance, renewable alternatives for energy-consumptive uses on ranges, and training simulation technologies. These technologies are necessary to minimize use of limited natural resources and reduce the training footprint on desert landscapes with low recovery resiliency.

References

Acevedo, W., L. Gaydos, J. Tilley, C. Mladinich, J. Buchanan, S. Blauer, K. Kruger, and J. Schubert. 2003. Urban Land Use Change in the Las Vegas Valley. U.S. Geological Survey, last modified Dec 2003 at: http://geochange.er.usgs.gov/sw/changes/anthropogenic/population/las_vegas/

Bailey, R. G. 1995. Description of the Ecoregions of the United States. 2nd ed. Rev. and expanded. Miscellaneous Publication No. 1391 (rev), USDA Forest Service, Washington, D.C., with separate map, scale = 1:7,500,000.

Belnap, J., and S. D. Warren. 2002. Patton's Track in the Mojave Desert, USA: An Ecological Legacy. Arid Land Research and Management, 16(3): 245-258.

Bischoff, M. C. 2000. The Desert Training Center/California-Arizona Maneuver Area, 1942-1944: Historical and Archaeological Contexts. Technical Series 75, Statistical Research, Inc., Tucson, Arizona.

Doe, W. W. III, R. G. Bailey, D. S. Jones, and T. E. Macia. 1999. Locations and Environments of U.S. Army Training and Testing Lands: An Ecoregional Framework for Assessment. Federal Facilities Environmental Journal, pages 9-26.

El-Baz, F. and R.M. Makharita, eds. 1994. The Gulf War and the Environment*.* Gordon and Breach Science Publishers, New York, New York.

Goran, W. D. W. W. Doe III, and B. Boesdorfer. Submitted. Military land use, dynamics and sustainability in the desert southwest. Proceedings, Desert Workshop, Zyzyx, CA.

Houston, S. T., W. W. Doe III, and R. B. Shaw. 2001. Environmental Risk of Army Ranges and Impact Areas: An Ecological Framework for Assessment. Federal Facilities Environmental Journal, Spring, pages 93-111.

Kolbe, J. (Congressman 8th District, Arizona). 2003. Congress Clarifies Fort's Water Responsibilities, Preserves Future of San Pedro River. Press Release, November 7, 2003 at http://www.house.gov/kolbe/press2003/030711_spr.html

Leake, S. A, A. D. Konieczki, and J. A. H. Rees. 2000. Ground Water Resources for the Future, Desert Basins of the Southwest*.* USGA Science for a Changing World, USGS Fact Sheet 086-00, August 2000.

Nabhan, G. P., and M. J. Plotkin. 1994. Introduction. Pages 5-8 in G. P. Nabhan and J. L. Carr (editors). "Ironwood: An Ecological and Cultural Keystone of the Sonoran Desert." Occasional Papers in Conservation Biology No. 1. Washington, D.C. USA: Conservation International.

Prose, Douglas. 1985. Persisting Effects of Armored Maneuvers on Some Soils of the Mojave Desert. Environmental Geology Water Science, 7(3): 163-170.

Shaw, et. al. 2000. Sustaining Army Lands for Readiness. Military Review, U. S. Army Command & General Staff College, Fort Leavenworth, KS, Sept-Oct 2000.

U.S. Army. 2006. Fort Bliss, Texas and New Mexico, Mission and Master Plan, Draft Supplemental Programmatic EIS, October 2006.

U.S. Army National Training Center, Ft. Irwin, CA, Land Expansion, http://www.fortirwinlandexpansion.com/, articles and data from 1997-2006

Webb, R. H. and H. G. Wilshire, eds. 1983. Environmental Effects of Off-Road Vehicles: Impacts and Management in Arid Regions*.* Springer-Verlag, Inc., New York, New York.

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
8-2008	Technical Report	

4. TITLE AND SUBTITLE

Proceedings from the DoD Southwest Region Threatened, Endangered, and At-Risk Species Workshop

5a. CONTRACT NUMBER

FA4890-04D-0009; W912DY-07-2-0007

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Dr. Julio Betancourt, Mr. L. Peter Boice, Dr. Matthew Brooks, Ms. Alison Dalsimer, Mr. Sean Donahoe, Dr. Todd Esque, Dr. John A. Hall, Dr. Andrew Hautzinger, Mr. Timothy Hayden, Dr. Susan Howe, Ms. Lainie Levick, Dr. Guy McPherson, Ms. Valerie Morrill, Dr. David Mouat, Dr. Leslie Orzetti, Dr. Michael Rosenzweig, Ms. Alicia Shepard, Dr. Thomas D. Sisk, Dr. Mark Sogge, Dr. Charles Van Riper, Dr. Larry Voyles, Mr. William Woodson

5d. PROJECT NUMBER

SERDP: AFC002-066; Legacy: HUN005

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

HydroGeoLogic, Inc.
11107 Sunset Hills Road, Suite 400
Reston, VA 20190

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Strategic Environmental Research and Development Program/
Environmental Security Technology Certification Program
Legacy Resource Management Program

Arlington, VA

10. SPONSOR/MONITOR'S ACRONYM(S)

SERDP/ESTCP,
Legacy

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

SERDP: DK03; Legacy: 07-377

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Many installations critical for military training and testing are located throughout the southwestern United States and provide essential habitat for numerous threatened, endangered, and at-risk species (TER-S). In October 2007, SERDP, ESTCP, and Legacy sponsored the DoD Southwest Region Threatened, Endangered, and At-Risk Species Workshop to (1) assess TER-S management needs within a regional context, with an emphasis on system-level and cross-boundary approaches; (2) assess these approaches for their potential to keep common species common while recovering or enhancing TER-S populations; (3) assess current understanding of the ecology of arid and semiarid ecosystems and how that does or should affect management approaches; (4) examine the current state of the practice within DoD for such holistic approaches; and (5) identify gaps in knowledge, technology, management, and partnerships that, if addressed, could improve implementation of such approaches. During the course of the workshop, discussions resulted in the prioritization of investment opportunities to address such gaps and management challenges.

15. SUBJECT TERMS

Southwest, TER-S

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	180	19b. TELEPHONE NUMBER *(Include area code)*